Light and emotion:

Exploring human affect in lighting

by Dong Hyun Kim

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Abstract

This thesis starts by questioning the efficiency of the current basis of lighting design practice on modern workspaces. The study argues the importance of shifting the basis of guidance from the types of spaces, and activities into human psychological states in the Introduction.

Both visual perceptions of the space and human emotion states are theoretically examined as a potential basis for lighting design practice. As a result, the human emotion state, ‘affect’, from the concept of the circumplex model of affect has been chosen as a better exploratory tool. Human ‘affect’ states of ‘lively’ and ‘relaxing’ were hypothesized mental states that people could benefit from in the workspace. A detailed field study, which consisted of two separate phases, was carried out to test the hypothesis.

In the first phase of the field study, a group of lighting designers was invited to devise a set of lighting design concepts that explore *activation* and *pleasantness* in the *circumplex model of affect* with the use of smart control of lighting. Then, the thesis investigated the design elements of the lighting settings as well as their photometric and colorimetric characteristics. The result indicated that although the design elements showed particular groupings, such characteristics were not effectively expressed using the current photometric and colorimetric variables.

In the second phase of the field study, 15 lighting settings in a controlled interior environment were set up based on the results of the first phase. A group of participants were invited to assess the settings by rating of their visual perceptions of the space and their emotion state. The results indicated that the settings inspired by the designers effectively affect human emotion states while providing high quality visual perceptions of the space. However, the two dimensions of human emotion, *activation* and *pleasantness*, did not provide, in detail, a statement of human emotion. Therefore, the thesis has proposed a new indicator that involved four different zones, defined by the two dimensions as an effective tool of measuring human emotional experiences from lighting.

In conclusion, the thesis successfully explores the possibilities of an emotion-based lighting design approach and explains their impacts by the field experiment as well as developing and investigating the effectiveness of a new indicator of human affect. The work described in this thesis would work as a fundamental but crucial step to promote human well-being in workspaces by fulfilling various human needs and the potentials of smart lighting technologies.

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Alvin Cousins Vince Kan Aticha Padungruengkit

Cehao Yu Nou Supantamart

I am also grateful to SUKWOO Engineering Inc. whose major gift generously supported me to purchase all the required materials to configure the experimental settings. With their help, the study was able to explore various lighting design options with up-to-date smart lighting technologies, which was later emerged into an experimental space. I am extremely grateful to all the people who generously gave me their time and shared their views with me, especially the participants for the experiment.

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Dedicated to my parents Jeong Tai Kim and Jin Young Lee

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Glossary of terms

Luminous flux	The quantity of radiant flux which expresses its capacity to produce visual sensation. Units: lumens (lm)
Luminous intensity	The luminous flux emitted in a very narrow cone containing the given direction divided by the solid angle of the cone, that is, luminous flux/unit solid angle. Units: candela (cd)
Illuminance	The luminous flux/unit area at a point on a surface. Units: lm/m^2
Luminance	The luminous flux emitted in a given direction divided by the product of the projected area of the source element perpendicular to the direction and the solid angle containing that direct, that is, luminous intensity/unit area. Units: cd/m^2
Correlated Colour Temperature (CCT)	A specification of the colour appearance of the light emitted by a lamp, relating its colour to colour of light from a reference source when heated to a particular temperature. Units: Kelvin (K)
Mean Room Surface Exitance (MRSE)	A measure of overall density of reflected luminous flux within a space. Units: lm/m^2
Human centric lighting	Lighting specifically designed to produce a beneficial physiological and/ or psychological effect upon humans.
Dynamic lighting	Lighting that varies its colour properties and its intensities
Smart lighting technology	Lighting that provides a connection to sensors, databases and allow wireless access to adapt, programme and provide for users within the environment.

Chapter 1

Introduction

"Let me give light, but let me not be light"

Portia, The Merchant of Venice

The phrase from "The Merchant of Venice" is too evocative to ignore. The thought of 'giving light' is clearly an abstraction but it is an exceedingly useful one from a lighting design and research perspective. '*Giving light'*... this phrase could symbolise a new philosophy of lighting design, a philosophy in the sense of how we think about the lighting design process. Much like the modernist movement in architectural design a century ago, it offers a reconciliation of lighting design practices with today's rapid technological advancements and societal changes.

The innovations we are seeing in lighting hardware today are not only fascinating but also part of a much larger movement known as the *Internet of Things.* Just as the first mobile phone has led to today's smartphones, the seeming unrelated innovations in solid-state lighting are about to lead us into a brave new world of lighting design that opens up a possibility of changing our philosophy of lighting design.

One might argue that we have already undergone such innovations in the past. Numerous paradigm shifts have occurred in the lighting industry over the past century or so, including gas lighting, incandescent lamps, fluorescent and high-intensity discharge lamps, solid-state lighting, and more. However, to the author, a light source is just that – a source of light. The question is: have we changed the way we think about light and lighting?

With our better understanding of the physics of light and lighting, we still have arguably a view of light as an intrinsic property of the light source. What if we consider light and lighting as an intrinsic property of ourselves? In this sense, we may abstractly 'give light' to the environments we happen to be in. The thought of us “giving light” is clearly an abstraction, but a useful one from our perspective. It means that it could shift the focus from designing the illuminated environment to designing for people. Therefore, we could give environments our desires and preferences in terms of lighting, including dynamic intensity and colour aspects.

What was just described is the concept of ‘personal lighting control’. A history of personal lighting control at the workspace dates back almost twenty years. Users can dim and switch downlights from the overhead luminaires, while integral occupancy sensors and timers can dim or switch off the lighting when the worker is not present. Lighting designers and other professions have therefore been enabling people to give light to their workspace environment for almost twenty years. It has been a fundamental change in how we think about light and lighting design. There has been a subtle change which has been barely noticed until recently.

Now, there seems to be an opportunity to take this change (or design philosophy) into a new and more exciting level with the arrival of smart lighting technologies and the *Internet of Things (IoT).* The Edge, which is an innovative, multi-tenant office building in Amsterdam, is a good example of how *IoT* technology has been applied to office lighting (see more information at http://www.lighting.philips.com/main/cases/cases/office/edge, accessed on 10th Jan 2018). At the Edge, nearly 6,500 connected LED luminaires create a ‘digital ceiling’ in the building’s 15 storeys. The system captures, stores, shares and distributes information throughout the illuminated space. Such stored and shared information not only allows the provision a customised illumination but could also increase human well-being, which is nowadays often referred to as ‘human-centric lighting’. The term often refers to lighting that considers both the visual and non-visual effects of exposing humans to light and that widens the range of possible effects from visual performance, comfort, sleep quality, mood and behaviour with consequences for human health.

The author argues that we may need to reconsider the basis of current lighting design practice for the workspace if we, as a lighting profession, want to take this opportunity for a meaningful change. Therefore, this thesis starts by questioning the potential of the current basis of lighting design practice in the workspace. It does not mean that the thesis claims that the current lighting design practice is flawed. What is argued is that the current lighting design practice has been heavily developed based on visual, functional, and economical values of lighting. Now, with the rapid development in lighting technologies, there is an opportunity to shift the focus of our current philosophy of lighting design, from providing a functional, economic value with some accent lighting to focus on users' emotional needs.

In summary, this study aims to investigate potential values of lighting on human emotion in the workspace. More specifically, the main research questions of this study are that (1) Could a set of lighting arrangements in the workspace cue various positive human emotion? (2) Could smart lighting technology be embedded in the lighting design process to further explore such an opportunity? (3) If so, could we identify the elements of lighting design or luminous conditions which are associated with positive or negative emotions? (4) Lastly, do the current assessment tools used in lighting studies effectively explore human psychological responses to dynamic light settings?

Chapter 2

Lighting quality: the usefulness of ‘affect’ models

This chapter reviews various studies on lighting quality parameters and indicators that are associated with human psychological experiences. Then, the chapter considers two different ‘affect’ models from emotion studies, the ‘Positive Affect Negative Affect Schedule’ (PANAS) and the ‘circumplex model of affect’, whether them to be an effective tool in exploring lighting design process and lighting quality assessment beyond the current lighting quality parameters.

2.1 A focus of the study: visual perception and moods

While there are various definitions of lighting quality made by many investigators, the thesis particularly adopts the concept suggested by Veitch and Newsham (1998; 2001).

They proposed a measurable definition of lighting quality (1998), which is “luminous condition that support the behavioural needs of individuals in the lit space”. With such definition, theoretically, lighting qualities could be measured in a number of criteria. Later in 2001, they expanded the components of lighting quality from human needs to architectural and economic aspects, which is shown in Figure 2.1. In the diagram, human needs are expressed as individual well-being and each component includes key sub-components. Although their definition of lighting quality is nicely addressing the key issues of wide aspects from human being and the built environment, this study narrows down its research interest into lighting quality on human factors at the workspace (displayed as individual well-being in Figure 2.1).

Assessing perceived lighting quality by workspace users would somehow be more difficult and more challenging than quantifying an economic value of lighting installation mainly due to individual differences in human needs. Consequently, a number of different parameters (or indicators) of key human factors have been widely studied and developed. Boyce introduced a simple concept of his idea on how to classify the overall quality of lighting installations in his book, *Human factors in lighting* (Boyce, 2013a).

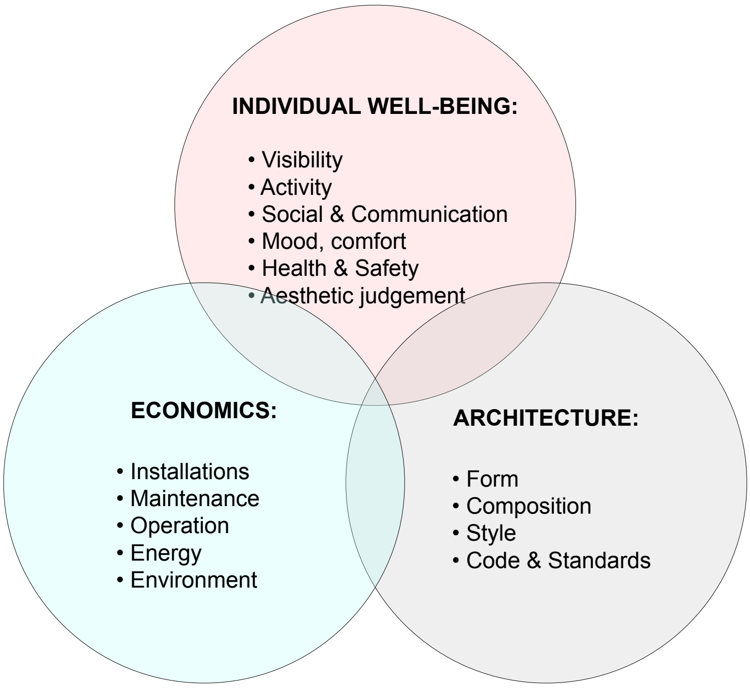

Figure 2.1. Lighting quality: the integration of individual well-being, architecture, and economics (Adapted from Veitch and Newsham (2001))

According to his concept, a lighting practice could be divided into three classes of quality: the *good*, the *bad* and the *indifferent*. *Bad* quality lighting is the one provides poor visual clarity of a task and causes visual discomfort. *Indifferent* quality lighting is lighting that provides an adequate level of light for a task without causing any visual discomfort but does not lift the spirit. Lastly, to be classified as *good* quality lighting, lighting should contain all of the elements of indifferent quality as well as raising the human spirit. He went on to argue that nowadays bad quality of lighting installation, especially in a modern office environment hardly exists due to the current lighting guidance and recommendation, which has effectively eliminated elements associated with poor visual clarity and discomfort source (Boyce, 2013a). Instead, most current lighting installations are between indifferent and good quality. Importantly, he claimed that good quality lighting seems to be frequently occurred at the conjunction of a talented architect and a creative lighting designer, neither of whom slavishly follows numerical lighting criteria from the recommendations.

Boyce (2013b) also summarised four different approaches being taken by lighting researchers in this matter to bridge the gap between indifferent and good lighting. These are (1) the development of more numerical lighting criteria, (2) more use of daylight, (3) changing the basis of design from the working plane to the whole space, and (4) giving occupants individual control of the lighting through the use of plug and play technology (technology that allows an electronic device to be used as soon as it is connected to a computer).

Although Boyce (2013a)'s simple classification of lighting quality has advantage of being easily applied to many different areas of lighting studies, his concept can be criticized as being too ambiguous. Particularly, the definition of the phrase, 'raising the human spirit', is very unclear. One might interpret this as feeling a positive emotion and another can understand this as increasing a cortisol level in their hormone.

After reviewing several concepts of lighting quality, this study has narrowed down its research focus on psychological responses to light and lighting and categorised the relevant literature areas into two variables, 'visual perception of a space' and 'human emotion (or affect)'. These two variable labels are a convenient, structured way of categorising the extensive research literature. Therefore, this chapter from now on has reviewed an impact of light and lighting on human psychological responses of 'visual perception of a space' and 'emotion' in a respective order.

2.2 Visual perception of space

2.2.1 Categorising perception

Visual perception of luminous environment might occur immediately but inevitably involve a complex process. In a short description, the *luminous environment* generates the *retinal image* which is the stimulus for the *process of vision* which provides information to enable the *visual perception process* to recognize the objects and surfaces that form the visual basis for the *perceived environment* (Cuttle, 2008). What makes studies in this area more complicated is that human perception of space is not only complex but also not stable.

Boyce (2013a) categorised visual perceptions of luminous environment into two sub-categories: simple perceptions and higher-order perceptions. Simple perceptions are the ones associated with fewer number of factors other than luminous environment than high-order perceptions. Therefore, simple perceptions such as brightness, lightness and colour appearance are likely to be more stable than high-order perceptions such as attractiveness and spaciousness.

In order to avoid misunderstanding, some definitions of the above perceptions are given as follows (Boyce 2013a):

- *Brightness* is a subjective attribute based on the extent to which more or less light is seen to be emitted.
- *Lightness* is a subjective attribute based on the extent to which more or less light is seen to be reflected
- *Spaciousness* refers to users’ perception of spatial volume of the space.
- *Colour appearance* refers to users’ perception of the overall colour appearance of the space.

His classification of visual perception of space is slightly modified in this study. Figure 2.2 shows the classification of visual perception made by the author. *Initial perceptions* are defined as the ones that are processed in a relatively short time after being exposed to the environment. On the other hand, *secondary perceptions* are defined as the ones that are likely to be influenced by multiple initial perceptions as well as many other factors.

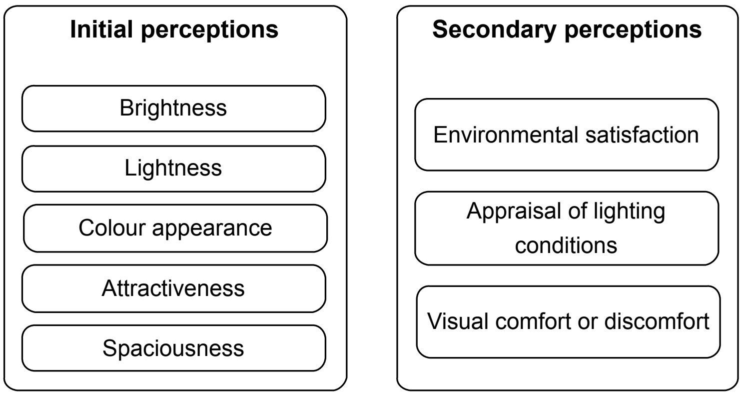

Figure 2.2. Initial visual perceptions of space and secondary perceptions

As shown in Figure 2.2, perceptions such as brightness, attractiveness, and spaciousness are categorised as initial perceptions whereas perceptions like overall satisfaction of environmental space, and appraisal of lighting conditions are categorised as secondary perceptions. After categorising perception of space, literature reviews of lighting on each perception follow.

2.2.2 Initial perceptions

The appearance of the lit environment has been one of the perceptions that many lighting profession do have investigated for several decades. Many attempts have been made to investigate what element of luminous condition influences human subjective appearance of space.

The classic example of the study in this area would be Flynn *et al.*’s (1973) early investigation of light on impression and behaviour. In their experiment, six different luminous conditions in a conference room were used as an independent variable. Flynn *et al.* initially obtained ratings on 34 semantic differential scales in response to six lighting configurations, and separate ratings of the similarity or difference between pairs of lighting configuration. They used factor analysis to reduce the semantic differential scales to three interpretable factors, which were named as ‘perceptual clarity’, ‘evaluation’, and ‘spaciousness’. Figure 2.3 shows their finding in three-dimensional diagram that was acquired to compare the results of factor analysis and multidimensional scaling results.

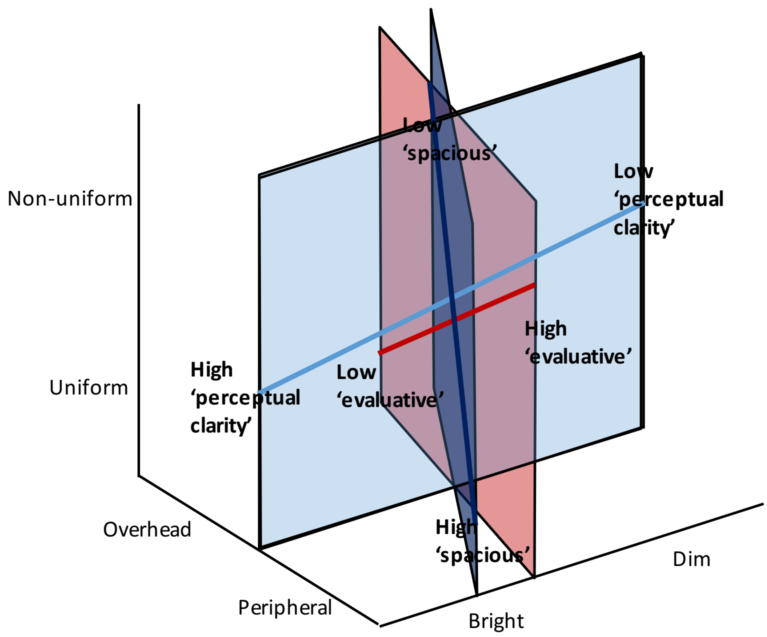

Figure 2.3. Three-dimensional diagram on visual impressions to lighting conditions (Adapted from Flynn *et al.* (1973))

In order to look into their finding in more detail, their results of factor analysis on the three perceptions was re-drawn, which is shown in Figure 2.4. As shown in the Figure 2-4, ‘evaluative’ perception mainly consisted adjectives that describe aesthetic aspects from illumination appearance whereas 'perceptual clarity' seemed to be more related with visual perception of brightness and lightness. One finding from their experiment is that human perceptions interacted with more than one factor of luminous conditions. More specifically, the factor of 'perceptual clarity' was mainly influenced by the light level on the horizontal plane as well as distribution of lighting playing a subsidiary part (see Figure 2-3). The result on the 'evaluative' factor showed that use of peripheral lighting on surface walls increased human perception of 'evaluative' factor such as beautiful, pleasant, interesting compared to the overhead downlighting conditions. Regarding the third dimension, 'spaciousness', providing light on the task table alone at a low illuminance made the room appear to be small and cramped whereas, illumination the walls alone or both walls and the task table gave an impression of a large and spacious room.

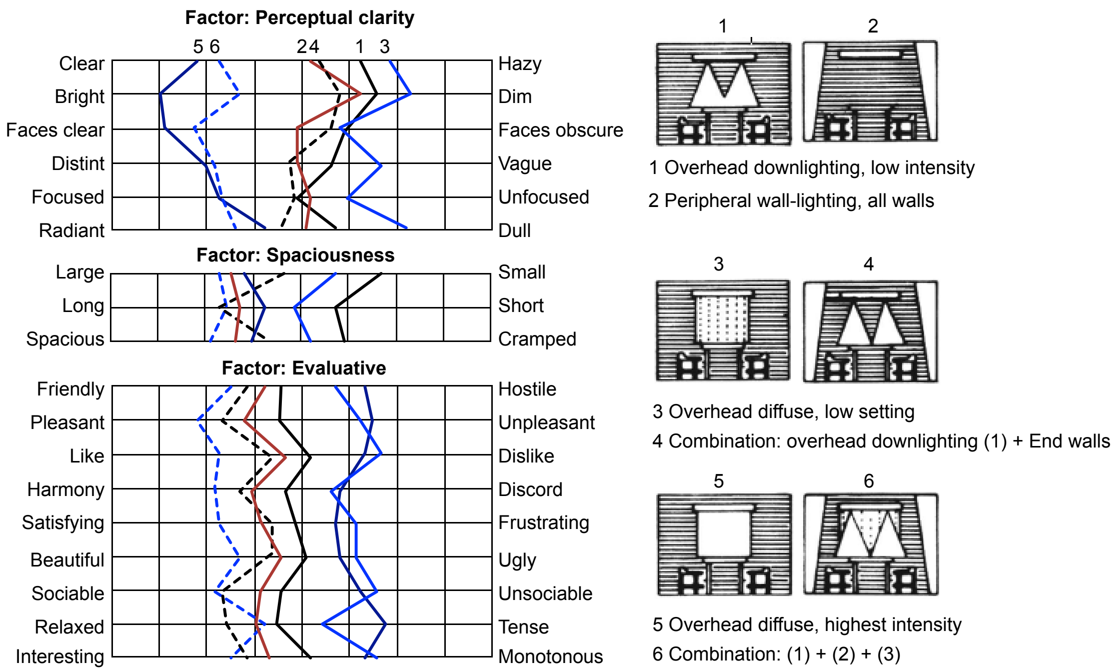

Figure 2.4. Three factors in perceptions and their components
(Adapted from Flynn *et al.* (1973))

In short, high illuminances were related to greater clarity, peripheral lighting and low illuminances produced a pleasant impression and the use of high illuminance and peripheral lighting produced an impression of spaciousness. Their results also show that the rating scale/factor analysis and the difference/multi-dimensional scaling (MDS) in lighting studies provided rich information about the perceptions of lit spaces, particularly used together. However, it should also be noted that all of these results came from one source. Therefore, before accepting such an important conclusion, the study also examined what others have found on this matter. There has been a series of investigations on this subject at the Bartlett School of Architecture at University College London (UCL) since the late 1970’s. Hawkes *et al*. (1979) showed that conditions segmented with sharp contours differentiated by the pattern of light and shade could make places more interesting and ultimately more preferred than the illumination made by regular arrays of recessed luminaires. They suggested that complexity (visual interest) and brightness together are perhaps the most important features of lighting design to make people more positive in their perceptions at least in windowless environments.

Later, Loe *et al.* (1994) examined the relationship between a subjective perception to a lit environment and its luminance distribution as a contribution to improving lighting design. In their study, 18 different luminous conditions in a full-scale mock-up conference room were used as an independent variable. Their study showed two main factors of visual perception of appearance, which were named ‘visual interest’ and ‘visual lightness’, as shown in Figure 2.5. The experiment showed that these two factors could be respectively described by the luminance contrast and the average luminance within a horizontal band 40^{o} wide and centred at normal eye height.

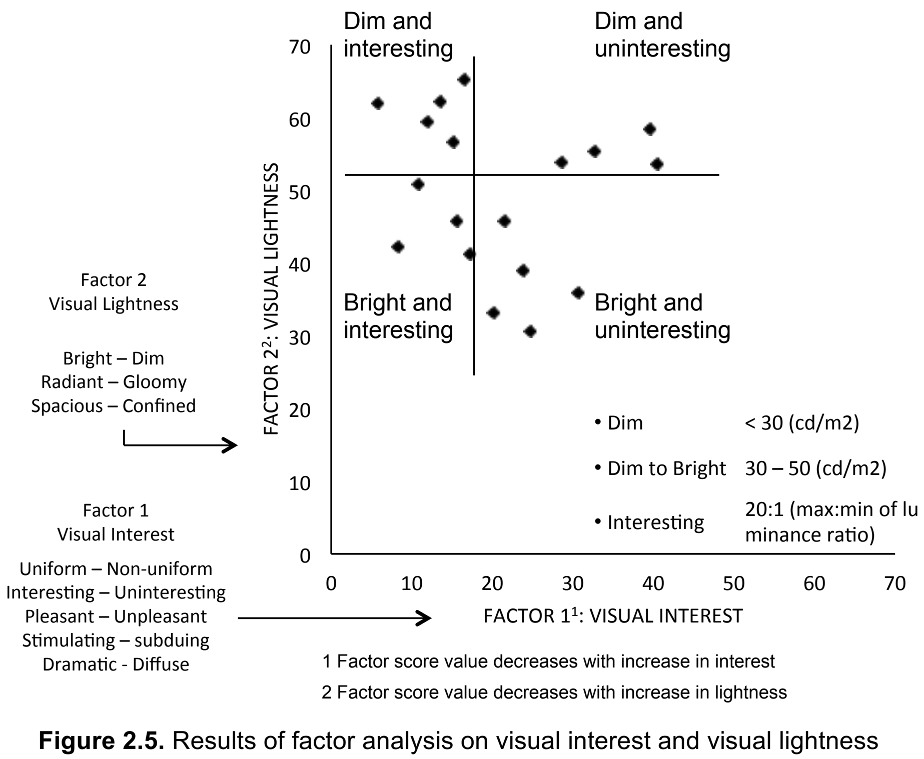

Figure 2.5. Results of factor analysis on visual interest and visual lightness (Adapted from Loe *et al.* (1994))

By comparing the findings from the Flynn *et al.*’s study, although a number of factors of perceptions reduced from three to two, there seems to be some common features between their findings. First, ‘visual interest’ mainly consisted of aesthetic aspects, which is similar to those Flynn *et al.* named as ‘evaluative’. Moreover, ‘visual lightness’ appears to be simpler version of a combination of ‘spaciousness’ and ‘perceptual clarity’.

Unlike Flynn *et al.*’s studies, Loe *et al*.’s findings suggested practical lighting design indicators to explore the appearance of lit environment, which are shown in Figure 2.5. According to their findings, a strong luminance contrast (more than 20:1 of luminance ratio) and bright wall surfaces could lead to a perception of ‘interesting’ and ‘bright’, which is more advanced from Flynn *et al.*’s earlier findings, in the author’s opinion. One interesting feature of their finding is that because their results suggested two-factor system, unlike three-factor from Flynn’s *et al.,* ‘visual lightness’ and ‘visual interest’ were completely independent variables[1]. If appearance of a lit environment were explained by two or three strong factors and if they were independent from each other, then we could use them separately as a basis for assessing lighting quality. However, it has been suggested by many other investigators that human appearance of lit environment is more complex than that.

Veitch and Newsham (1998) conducted an experiment as an attempt to verify the above findings. They recruited 292 participants and asked them to rate the appearance of an open-plan office lit under nine different light settings. In their experiment, 27 semantic differential (SD) scales were used to measure participants’ subjective perceptions. The results of principal components analysis were not the same as either Flynn *et al.*’s study or Loe *et al*.’s study, which is shown in detail in Table 2.1.

As shown in Table 2.1, three different components (or factors) of perceived appearance were acquired, which were named as ‘visual attraction’, ‘complexity’ and ‘brightness’. According to their findings, ‘visual attraction’ seems to be a similar factor to ‘evaluative’ and ‘visual interest’ except that uniform-nonuniform in this case was classified as a part of different factor, ‘complexity’. The ‘brightness’ was again found to be an important factor in perceived appearance. The ‘complexity’ was a factor that was not reported in either Flynn *et al.* or Loe *et al.*’s studies. Most importantly,

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[1]Note: One of the original investigators of the Loe *et al.* (1994) has indicated that a third (weak) factor was indeed extracted but did not weight heavily on the assessment scales. (Private communication with Kevin Mansfield)

they concluded that even though three main components were identified to explain perception of appearance, all of the three components (or factors) only accounted for approximately 40% of total variance. Considering the fact that 27 pairs of semantic differential scales, which were built based on a relevant theoretical basis were used in the study, identifying key components of human perception of luminous environment is still in a need for an improvement.

Table 2.1. Results of components analysis of room appearance (27 SD scales)
(Adapted from Veitch and Newsham, (1998))

	Visual attraction	**Complexity**	**Brightness**
Like – Dislike	0.837		
Pleasant - Unpleasant	0.836		
Beautiful – Ugly	0.825		
Attractive – Unattractive	0.820		
Interesting – Monotonous	0.767		
Colourful – Colourless	0.724		
Comfortable – Uncomfortable	0.718		
Subdued – Stimulating	-0.673		
Gloomy – Radiant	-0.611		
Spacious – Cramped	0.610		
Somber – Cheerful	-0.608		
Tense – Relaxing	-0.540		
Distinct - Vague	0.505		
Cluttered – Uncluttered		-0.610	
Nonuniform – Uniform		-0.589	
Constant – Flickering		-.569	
Complex - Simple		-0.515	
Bright – Dim			0.655
Glaring – Not glaring			Statistically not strong to be classified as a factor
Warm – Cool			
Overhead – Peripheral			
Large – Small			
Dramatic – Diffuse			
Faces clear – Faces obscure			
Public – Private			
Formal – Causal			
Clear - Hazy			
Variance Explained (%)	28.77	9.27	6.18

Vogels (2008) investigated human perception of atmosphere perception in a different way that the above studies approached. First, in order to develop her own set of descriptors, she recruited 42 participants and asked them to describe their perceptions of daily lives of a space. In total, 184 descriptors were collected and were then narrowed down to 38 based on the frequency. Then, she used the 38 descriptors with a 7-point scale to test different group of participants' perceptions through several series of experiments including a real field study, a mock-up fashion shop, and an empty room with 11 different light settings. As a result of factor analysis, she extracted four different components (or factors) from the participants' perceptions, which were quite different from the findings from the other reviewed studies. She named her questionnaire as 'atmosphere metric' and instead of using the terminology of perception of appearance she called her results as 'atmosphere perception'. Figure 2.6 illustrates four factors from her findings. She went to argue that human affect is more unstable than atmosphere perception and therefore atmosphere perception should be used as a basis to assess human psychological experiences of environment.

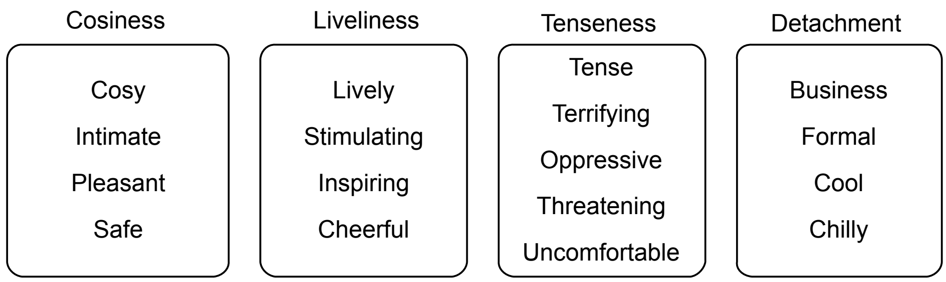


Figure 2.6. Four factors of atmosphere perception
(Adapted from Vogels (2008))

First, as shown in Figure 2.6, Vogels's descriptors in atmosphere perception consists several emotion-descriptors rather than typical descriptors for describing appearances. For example, 'threatening' appears to be more of emotion-descriptor in relation with negative and high arousal state rather than describing appearance of atmosphere. Therefore, Vogel's four-factor 'atmosphere perception', in the author's opinion, is a mixture of both human affect state and appearance of the environment. However, considering that her experiment included various different indoor environments such as a fashion shop, a bank, a restaurant, a sport facility and an office might have been the reason why it differs so much from the above studies, which mainly considered either a conference room or an open-plan office.

Aside from the studies on human complex perception of space, a perception of brightness solely has long been an issue for lighting researcher. A large number of studies on how to interpret precisely our perception of brightness have been conducted, which has led to development in its related illumination metrics. For example, average horizontal illuminances at the task plane was initially believed to be a good indicator of perceived brightness and average luminance on wall surfaces, or in the field of view were also considered to be an indicator. Later, metrics that includes spectral power distribution (SPD) of light sources such as a ‘S/P ratio’ (Berman *et al.,* 1990) or ‘$P*(S/P)^{0.5}$’ have also been proposed to explain out perception of ‘spatial brightness’. The term, ‘spatial brightness’ here means the visual sensation of the magnitude of the ambient lighting within an environment such as a room (Fotios and Atli, 2012; Fotios *et al.,* 2013). Although investigators such as Royer and Houser (2012) think such illumination metrics are still in a need of revision to improve their precision, it seems very clear that the lighting profession has made a significant improvement in this matter. Although the developments in this matter have hugely improved our understanding of human perception of brightness and has potential to lead to a more energy efficient solution than conventional lighting guidance (Fotios, 2013; Uttley *et al.,* 2013), it is also argued that the focus of lighting design practice should be expanded into the whole appearance of the space by a holistic approach.

In recent years, Cuttle has consistently argued that we should expand our attention to the appearance of the space rather than fixating on the lighting of a horizontal working plane. In short, his argument (Cuttle, 2008; 2010; 2013; 2015; 2016) is there is hardly a case of causing visual difficulties in most of workspaces especially with the development and increasing use of self-luminous devices. Therefore, he has claimed that in the early stage of lighting design, we should more focus on lighting appearance, with the concept of ‘perceived adequacy of illumination’ (PAI) being used as the basis for lighting recommendation. The metric he associates with this criterion is ‘mean room surface exitance’ (MRSE, lm/m^2) as measured from the position of the observer’s eyes. This metric ignores direct light from the luminaires and considers only light reflected from the room surfaces. More specifically, MRSE indicates both the average flux density emerging from surrounding room surfaces, and the average level of diffused field of inter-reflected light within the volume of a space (Cuttle, 2010). Cuttle (2013) also suggested an additional criterion called ‘target/ambient illumination ratio’ (TAIR) and a design procedure for first lighting the space and then any significant objects in it. He called such approach in lighting practice as ‘perception-based design approach’ in his book, *Lighting Design: A Perception-Based Approach* (2015).

Here is a more specified summary of his approach. PAI, which is specified in terms of MRSE, should be prime criterion for indoor lighting practice according to his argument. It should be borne in mind that MRSE indicates density of reflected light, *not* incident light and a value of MRSE is an ambient quantity, not related to a particular plane, position or direction of view. Most importantly, once the PAI criterion is satisfied (either by manual calculation or computer simulation), an architect or lighting designer has the freedom to prioritise their design objectives, which may be supported by some of his suggested TAIR ratios. As MRSE is a metric that Cuttle proposed, he also gave his idea of reference value of it, so lighting designers could use them to predict whether his or her design provides more than acceptable perception of brightness. Table 2.2 shows the reference values of MRSE and TAIR ratios (Cuttle, 2013).

Table 2.2. Approximate guide to perceived brightness and visual emphasis related to MRSE and TAIR (Adapted from Cuttle (2013))

MRSE (lm/m^2)	Perceived brightness	TAIR	Visual emphasis
10	Lowest level for reasonable colour discrimination	1.5:1	Noticeable
30	Dim appearance	3:1	Distinct
100	Lowest level for ‘acceptably bright’ appearance	10:1	Strong
300	Bright appearance	40:1	Emphatic
1000	Distinctly bright appearance		

Although the author agrees with an idea that light level on a horizontal working plane becomes a less important indicator of lighting quality in modern workspaces as most of the visual tasks in nowadays involve a self-luminous screen device, there are several limitations on a practical use of MRSE as an alternative metric. First, an MRSE does not consider any of room geometry in its calculation process. Theoretically, a single value of MRSE can only be calculated per an enclosed space. Therefore, if room geometry is an important issue, MRSE does not provide much of useful information. Another limitation is that his concept of MRSE was built on an enclosed interior space. However, unenclosed spaces do not generate diffusely inter-reflected light fields, and so the MRSE concept would not be applicable.

2.2.3 Secondary perceptions

As defined earlier in this study, secondary perceptions are the ones that are influenced by both several initial perceptions and other external factors. Overall preference of a space, overall satisfaction level of a space are the examples of the defined secondary perceptions in this study. Compare to the studies on initial perceptions, an understanding of the effects of lighting condition on occupants’ various secondary perceptions is vague. In particular, questions remain as to the possibility that lighting conditions might be further improved beyond the visual task recommendation level to the point at which they could become positive contributors to employee productivity, mood and psychological well-being (Boyce, 2004).

Several investigations have pointed out the effects of lighting distribution and the availability of individual control on various human psychological responses. In terms of lighting distribution, a number of studies have suggested that the use of both direct and indirect lighting was preferred over direct-only systems (Boyce *et al.,* 2006; Houser *et al.,* 2002; Veitch *et al.,* 2000) although Fostervold and Nersveen (2008) found very few statistically significant effects of different proportions of direct and indirect lighting on office workers’ health, well-being and cognitive performance.

Regarding the effects of individual control, it was reported that individually controllable lighting conditions were rated as more comfortable by a larger percentage of people than conventional fixed condition (Boyce *et al.* 2006). However, Veitch and Newsham (2000) reported no simple effects of individual control over lighting on task performance, mood, or satisfaction. Later Veitch *et al.* (2008) reanalysed the data without control and found that people whose working conditions were more close to their personal preference showed improved mood and higher ratings of lighting satisfaction and overall environmental satisfaction.

Based on the above literature, it seems that although changes in some components of the lit environment affect occupants’ or employee’s psychological responses, the path from the lit environments to employees’ workplace psychological well-being is not clear. Veitch *et al.* (2010) argued that there have been only a few formal attempts to develop relevant analytical descriptions of a linkage between the physical variables of the lit environment and various human behavioural outcomes.

One attempt to link the lit environment and the psychological effects of light and lighting was the introduction of the *linked mechanisms* map (Wyon, 1996). This is a logical structure that attempts to set out the paths by which the independent variables influence the dependent variables. Boyce *et al.* (2006) built a hypothetical linked mechanisms map (Figure 2.7) to investigate the effects of lighting condition and individual control on various human responses. In their study, it was shown that different lighting installations were perceived differently, that conditions that improved the visibility of tasks led to better task performance and that individual control over the lighting improved motivation and well-being.

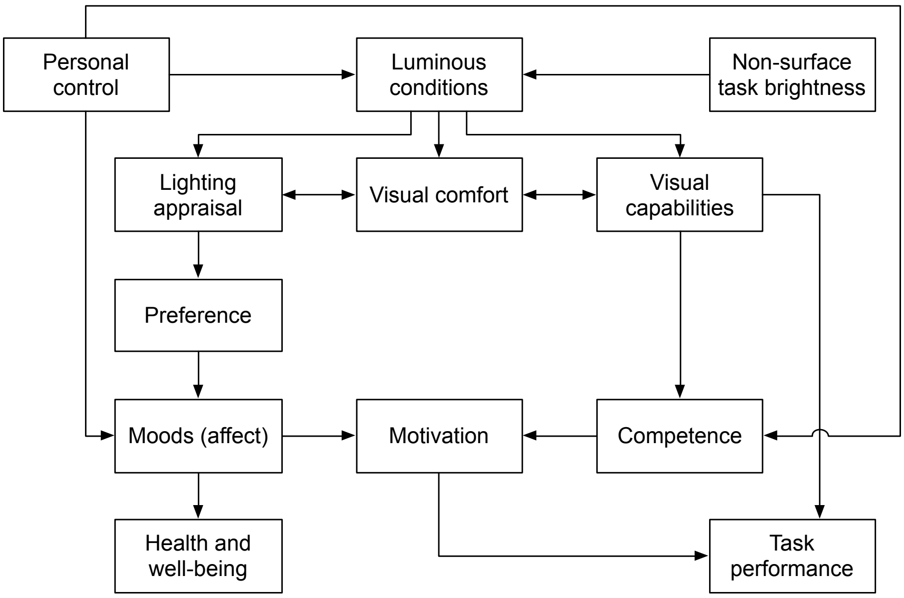


Figure 2.7. A hypothetical linked mechanisms map
(Adapted from Boyce *et al.* (2006))

Later, Veitch *et al.* (2008) reanalyzed the data reported by Boyce *et al.* (2006) and suggested the modified linked mechanisms map from a series of mediated linked regressions, as shown in Figure 2.8. In the modified linked mechanisms map, two paths were found with statistical significance; 'appraisal path' and 'vision path'. The vision path showed that the preferred lighting conditions influenced task performance both directly and indirectly. Interestingly, the result suggested that preferred luminous condition directly increased visual capabilities which led to higher task performance. On the other hand, preferred luminous conditions resulted in more attractive perception of lighting, which decreased users' motivation level unexpectedly and led to a decrease in task performance.

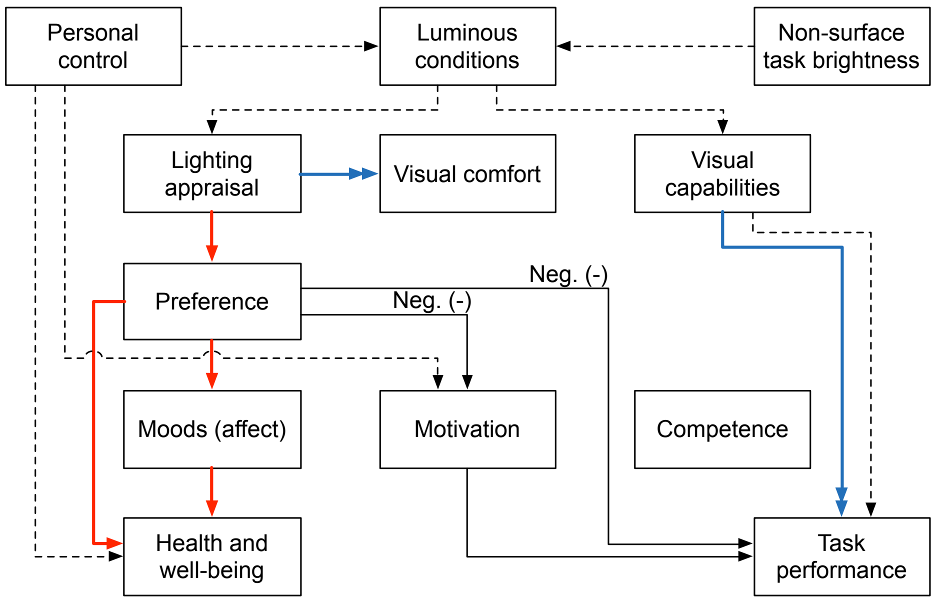


Figure 2.8. The modified linked mechanisms map (Adapted from Veitch et al. (2008))

Note: the map shows lighting condition test results with dotted lines, and mediated regression test results with solid lines. Red solid lines show the 'appraisal path' and the blue solid lines with double-headed arrows show the 'vision path'.

Another path, the appraisal path, was the most strongly supported in their study. This path led from the appraisal of lighting quality towards judgements of the preference of the space. This, in turn, led to an improvement of mood (affect), which in turn predicted end-of-day physical and visual health and well-being. In their study, health and well-being was defined as a sum of measured environmental satisfaction and self-perceived eye discomfort. According to their result, it could be argued that human perception of lighting appearance is more of a key variable in whole psychological pathway than perceived moods, as it is linked with both motivation and health and well-being as well as influencing moods.

Veitch *et al.* (2011) re-analysed the psychological pathway (the linked mechanisms map) model but with a different set of data compare to the earlier study. The data used in their re-analysis was from studies of Newsham *et al.* (2003; 2004). Instead of using regression analysis, they used structural equation modeling (SEM) technique to refine the model, and their revised model is shown in Figure 2.9. Unlike their previous result, the model showed that perceived moods (pleasure) was not linked with environmental satisfaction but linked with willingness of work engagement such as motivation.

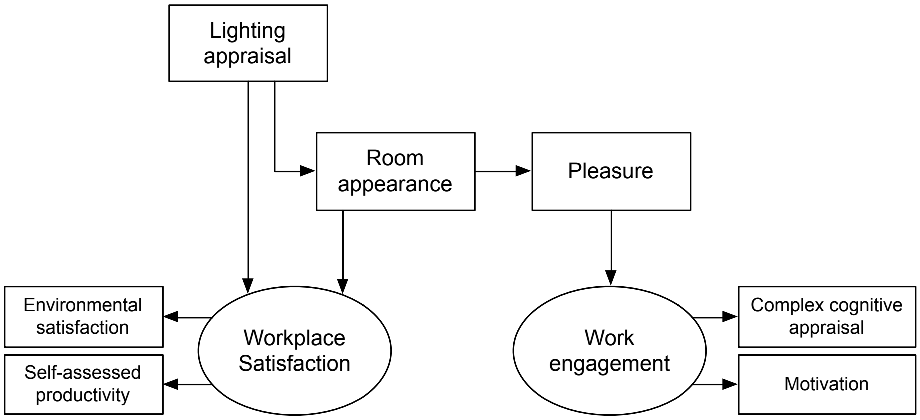


Figure 2.9. A psychological pathway linking lighting appraisal to work behaviours (Adapted from Veitch *et al.* (2011))

Kim and Mansfield (2016) pointed out that the appraisal path studies were all based on controlled experiments with almost no presence of daylight. Therefore, they investigated the potential influence of daylighting on perceived lighting quality and its subsequent effect on occupant health and well-being in uncontrolled indoor environments. Their result showed that in the daylit environment, occupants were less sensitive to perceived lighting quality than in the non-daylit indoor space where a strong correlation is demonstrated with health and well-being. Their result suggested that users under a well-controlled daylit environment is likely to have higher perceptions of health and well-being than the occupants under a non-daylit environment. In summary, Kim and Mansfield (2016) found a different pathway under the real uncontrolled environment.

All that can be confidently concluded from the above studies is that changes in luminous environments would have clear influence on both human perception of space appearance and perceived moods. However, a psychological pathway of linking them is still largely unclear and our knowledge on constructing factors of perceived appearance is also limited. The chapter now reviews the effects of luminous environments on human emotion or moods.

2.3 Moods (affect)

2.3.1 Affect models

It is widely known that light and lighting influences human emotion, moods or feelings in direct and indirect ways. Before this study closely looks into the literatures on human emotion and affect from a lighting perspective, it first needs to be clarified that what do we mean by an emotion in this context.

A number of studies have defined *emotion*. One common definition is as “brief, adaptive responses, involving physiological and cognitive reactions to objects, people, or situations” (Niedenthal *et al.,* 2006). Another is as “a multicomponent response to a challenge or opportunity that is important to an individual’s goals” (Oakley *et al.,* 2006). However, such definitions do not help us to effectively distinguish emotional states from other mental states. Therefore, this thesis refers to emotion as an internal mental state consisting of various subjective feelings of pleasantness or unpleasantness.

Aside from defining emotion, psychologists often make further distinctions among *affect*, *emotion* and *mood*. Simply put, affect is generally pleasant or unpleasant and emotions are more defined types of pleasantness or unpleasantness, such as happiness or surprise, sadness or anger or fear, which are typically accompanied by physiological arousal, as well as behaviour that expresses or copes with the emotional states. Lastly, moods are often explained as pervasive, global feelings, with relatively low intensity.

It is very often noticed that these terms are used interchangeably and this thesis will also do this, but the purpose of the brief explanation here is to remind that this study is aware of the technical distinctions among these affective states.

Wilhelm Wundt, who was primarily interested in the structure of sensory experience, turned his attention to the problem of the structure of emotional experience, and argued that any emotional experience could be decomposed into three dimensions, which are *pleasantness-unpleasantness*, *excitement-calm*, and *strain-relaxation*. Later, Mehrabian and Russell (1974) proposed that two independent orthogonal dimensions effectively accounts for the differences among the various emotional states. The first of these, following Wundt’s introspective analysis, was defined as *pleasantness-unpleasantness.* The second dimension was defined by *high arousal-low arousal (or often stated as activation-sleepiness)*. Russell (1980) later suggested that the various emotional states demonstrate what is called a circumplex structure. A circumplex is a circular arrangement of objects such that the angular distance between them represents the correlation between them. That is, emotional states that are close together on the circumplex are very similar to each other, or very likely to co-occur. His finding as a circumplex structure of emotional states is called the 'Circumplex Model of Affect', which is shown in Figure 2.10. Again, as can be seen from Figure 2.10, Russell (1980) used the same two orthogonal dimensions in the model.

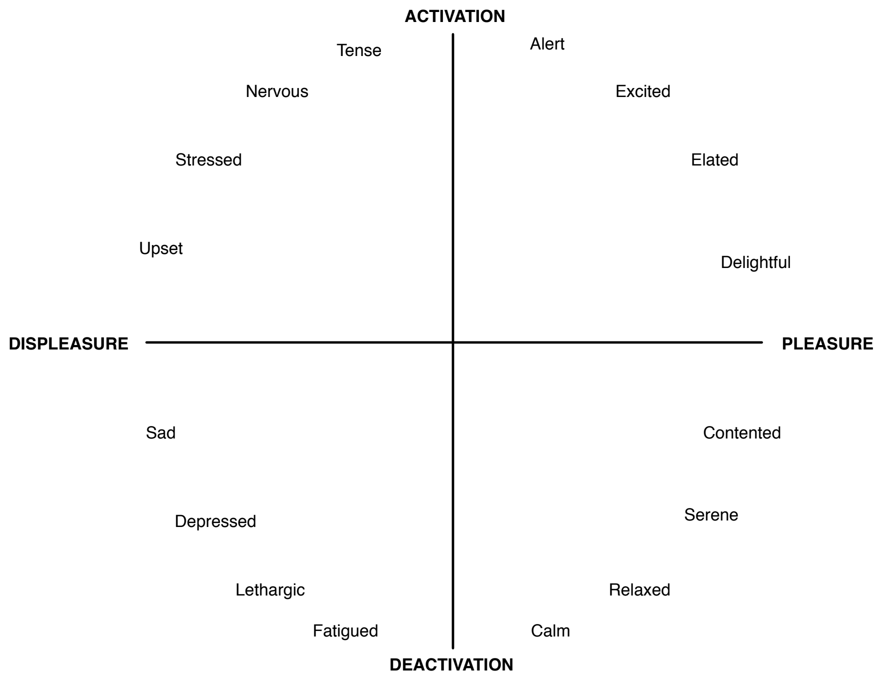


Figure 2.10. The Circumplex Model of Affect
(Adapted from Russell (1980))

Then, how do the researcher measure perceived human affect or emotion based on the circumplex model? In many of Russell and his colleagues' studies, participants were asked to rate their feelings on pre-chosen adjectives through 5-rating scales in either a 'strongly agree' to 'strongly disagree' format or a 'not at all' to 'extreme' format. A number of adjectives involved in this matter often consisted of more than fifty adjectives, which may provide higher precision of measured human affect but inevitably such method requires substantial amount of time for measurement.

Therefore, Russell (1980) suggested a simplified technique that participants self-report to an investigator their feelings on two dimensions, *pleasure* and *activation* directly via 9-likert scales.

He later also further proposed the way of measuring human emotions by asking a single-item scale of pleasure and arousal, called the ‘Affect Grid’ (Russell, 1989), which is shown in Figure 2.11. According to Russell, the affect grid showed strong evidence of discriminant validity between the dimensions of pleasure and arousal although due to its simplicity it appears slightly less reliable than a multiple-adjective questionnaire for self-reported mood.

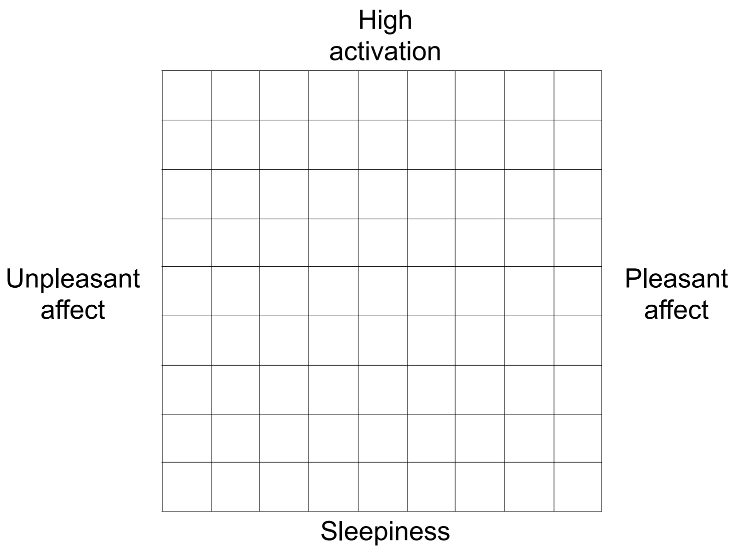


Figure 2.11. The affect grid

(Adapted from Russell (1989))

As intuitively appealing as the Russell’s circumplex model is, there are several different points of views on the structure of emotion states. Watson and Tellegen (1985), for example, performed the same sort of analysis and demonstrated a similar basic two-dimensional structure of human emotional states but they named them quite differently. One dimension is defined by *high vs. low positive affect (PA)* and the other dimension is defined by *high vs. low negative affect (NA)*. Watson and Tellegen argued that the affects were *descriptively bipolar* – that is, positive vs. negative – but *affectively unipolar.* According to their emotion model, only the high end of each dimension represents emotional arousal whereas the low end reflects the relatively absence of affective involvement. The model that they have argued for is called the ‘Positive Affect and Negative Affect Schedule (PANAS) model’, which is shown in Figure 2.12.

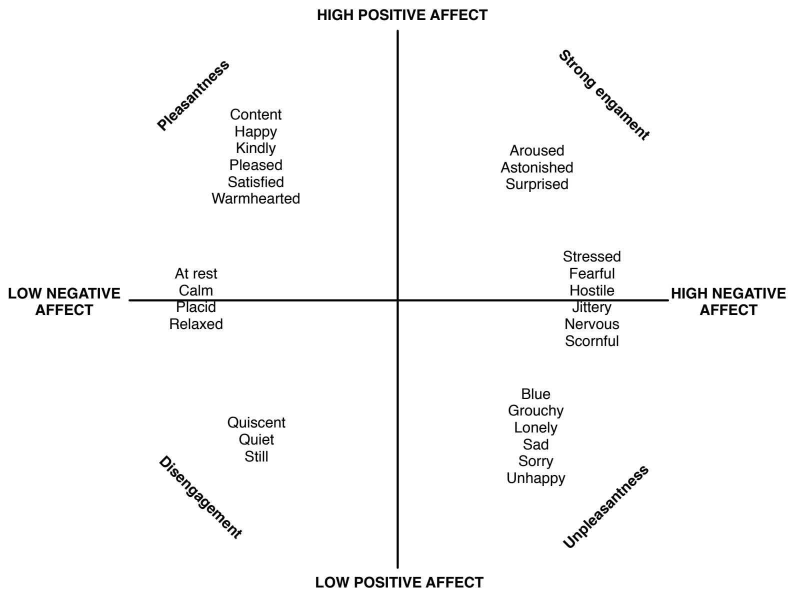


Figure 2.12. Positive Affect and Negative Affect Schedule (PANAS) model

(Adapted from Watson and Tellegen (1985))

Again, what is a practical tool for measuring affect state based on this model? Watson *et al.* (1988) suggested a specific set of questionnaires to be used in this matter, called the PANAS scale. The PANAS scale consists of 20 different adjectives, in which each 10 adjectives are assigned to calculate the score of PA and NA. A 5-rating scale for each adjective is often used. Figure 2.13 shows a cropped image of the PANAS scale.

The fact of the matter is that two models (the Circumplex Model of Affect, and the PANAS model) show very close agreement to the circumplex structure, but the primary difference is that **whether positive and negative affect lies on separate dimensions (the PANAS model) or on opposite ends of a single dimension (the Circumplex Model of Affect)**. Could we have both positive and negative affect states? It wouldn’t be possible if they were polar opposites. However, whether which model structure is more theoretically strong is not the argument that this study is making. Rather, this thesis is interested in the application of affect models in the lighting design practice and quality assessment.

In summary, this section reviewed theoretical backgrounds of the two affect (or emotion) models, the ‘circumplex model of affect’ and the ‘PANAS model’. The models were particularly selected with following reasons. First, these two models have been widely applied in many lighting studies already and therefore it is possible to conduct a critical analysis based on the findings from previous studies. Second, both models, as explained earlier in this section, are built on very similar theoretical idea that human affect (or emotion) can be expressed in a two-dimensional space, which provides an opportunity to compare their findings. First, the review focuses on lighting studies that adopted the concept of PANAS model mainly by using a PANAS scale.

1	2	3	4	5
Very Slightly or Not at All	A Little	Moderately	Quite a Bit	Extremely

__________ 1. Interested	__________ 11. Irritable
__________ 2. Distressed	__________ 12. Alert
__________ 3. Excited	__________ 13. Ashamed
__________ 4. Upset	__________ 14. Inspired
__________ 5. Strong	__________ 15. Nervous
__________ 6. Guilty	__________ 16. Determined
__________ 7. Scared	__________ 17. Attentive
__________ 8. Hostile	__________ 18. Jittery
__________ 9. Enthusiastic	__________ 19. Active
__________ 10. Proud	__________ 20. Afraid

Figure 2.13. The PANAS scale (20 adjectives)
(Adapted from Watson *et al.* (1988))

2.3.2 Positive affect and negative affect Schedule (PANAS)

There have been a large number of lighting studies that adopted the PANAS model and therefore this study first starts reviewing some of 1990’s to 2000’s studies first and then looking into more recent studies.

Related studies from 90’s to 00’s

In 1992, Baron *et al.* varied illuminance (500 lux and 1500 lux) and CCT (3000K and 4200K) of light setting and asked participants to fill in the PANAS questionnaire. As a result, no significant effect was found on the PA and NA scale. The only finding was a non-significant trend that the participants liked the 3000K setting slightly more than the 4200K lighting setting. The experiments were then repeated with a different set of questionnaires that consisted of ten bipolar emotion scales. This time, a significant interaction between illuminance level and CCT was found for the *anxious-calm* and *sleepy-awake* dimensions, which was that participants felt calmer and less awake in the 500 lux condition, compared to the 1500 lux condition when the lighting was set to

3000 K. What Baron *et al.* (1992)’s study can suggest is that first PANAS scale might not be a suitable tool of a questionnaire that investigates an impact of lighting on human emotion especially compare to the scales of *anxious-calm* or *sleepy-awake*. More critically speaking, the PANAS scale consists of 20 adjectives (see Figure 2.13) and some of the adjectives such as ‘guilty’, ‘proud’, and ‘afraid’ does not seem to be most appropriate to explain the feelings of participants when lighting conditions were changed from 1500 lux to 500 lux.

Knez (1995a; 1995b) also conducted a two of experiments on the effects of CCT and illuminance level on emotional experiences. His result (1995a) showed that females’ NA decreased at 3000K, but mens’ NA decreased most at 4000K of lit environment. On the other hand, Knez (1995b) found no effect of illuminance on positive or negative affect, which is consistent with a later study of Hygge and Knez (2001). Knez and Kers (2000) again tested the effects of lighting on emotion using the PANAS scale and this time their results showed that only the negative mood was altered, differentiated across age group but not across gender. The younger participants were shown to preserve the negative affect in the warm and least well in the cool white lighting while working with 90-min cognitive tasks. For the older participants, however, the reverse effect was observed. In addition, Knez and Hygge (2002) investigated the effects of CCT on affect with using another self-reported affect scale and no effect was found. Moreover, McCloughan *et al.* (1999) reached the same conclusion as Knez (1995a) for the female case but they also suggested that there is an increase in negative affect at high illuminances for cool CCT lamps, and negative affect decreased with warm CCT lamps at high illuminance. What can be suggested from the above findings is that the PANAS scale shows inconsistent results when investigating an impact of CCT variations between 4000K and 3000K. It can be assumed that either the PANAS scale was not most appropriate tool in their study or their variation of CCT (3000K to 4000K) was not a strong enough stimuli to cause any of meaningful emotional impacts.

Veitch *et al*. (1991) and Veitch (1997) also conducted a series of experiments to test the lamp type effects on moods using the PANAS scale. In their study, a full spectrum fluorescent lamp did not produce improved moods (no changes in positive affect and negative affect). They also reported that low illuminance and warm white light settings tended to be somewhat more favourably rated, but there were no systematic differences in ratings of either positive or negative affect in relation to the lighting conditions on the PANAS questionnaire measure.

Basically, many studies in this matter kept showing inconsistent results. It could either be said that the effects of lighting on human affect or emotion is difficult to be standardised due to individual differences or that measuring scale of affect (the PANAS scale) as applied to lighting is questionable. Interestingly, most of studies reported changes in negative affect, but rarely reported changes in positive affect at least in the author’s view.

However, many of the reviewed studies such as Knez (1995a; 1995b, 1997), Veitch (1991; 1997) are based on conventional fluorescent lamp settings, which are nowadays rapidly being replaced by LED-based lighting systems. Therefore, this study also reviews more recent studies that either includes various psychological variables such as well-being or a use of up-to-date LED-based lighting systems.

<u>Recent studies since 2010</u>

Plitnick *et al.* (2010) investigated the effects of different spectra of lighting on alertness and mood at night. This study differed from other experiments that used mock-up type offices as their experimental space in using a small light box ($0.6*0.6*0.6m^3$) that was fitted with arrays of LEDs. Therefore, it could be said that their study specifically focused on the effects of 470 nm (blue) LEDs and 630 nm (red) LEDs on emotional responses. Regarding the measurement of emotional responses, sleepiness and alertness were self-assessed by a Karolinska Sleepiness Scale (KSS) and a modified Norris mood scale. The KSS scale is a 9-point standardised sleepiness scale ranging from ‘extremely alert’ to ‘very sleepy, fighting sleep’, which theoretically shares the same concept from the activation dimension of the circumplex model of affect. The original Norris mood scale is comprised of 12 items of 7-rating scales; however, in their study, one single scale of alertness (-3 to +3) was adopted. Then, the PANAS scale was used to measure subjects’ positive and negative affect as well as their brain activity by measuring electroencephalogram (EEG) frequencies. In their experiment, participants were exposed to four different experimental lighting conditions; two spectra (blue and red) at two different light levels (10 lux and 40 lux) and rated their responses prior to, during and after light exposure. The results showed that the blue light at 40 lux had more impact on reducing sleepiness (a decrease in the KSS score) and an increasing positive affect score on the PANAS scale than did the blue light at 10 lux. A different pattern resulted from the red light exposures. Red light at 10 lx had a greater impact on reducing sleepiness and improving positive affect than did the red light at 40 lux.

Figueiro *et al.* (2011) also investigated the effects of spectral of lighting on various emotional and physiological responses. In their study, a group of students were asked to wear orange glasses during the class, which minimised the short-wavelength light exposure and reported their sleep qualities and emotional responses as well as their melatonin measurement for a week. Then, their results were compared with another group of students who did not wear the orange glasses at that time. Again, the PANAS scale was mainly used to record participants’ subjective emotional responses. The result showed that there was no statistically significant difference in reported emotion (referred to as ‘well-being’ in their study).

Both of the two studies investigated the effects of spectra of lighting on emotional or affective state responses while circadian rhythm and other physiological responses were also considered. Although their findings suggested contradictory results, this is difficult to conclude that the impacts of lighting on human emotion is inconsistent. Because, first, their research designs (one was conducted under a controlled environment, another was under an uncontrolled real environment) differed hugely, which makes difficult to compare their findings. Second, it can also be assumed that subjective emotional response from different spectra of lighting is more sensitive under a short-term exposure of lighting than a long-term of exposure.

Moving to more recent studies, Denk *et al.* (2015) investigated the effects of different CCT (4200K and 5000K) on shoppers’ psychological experiences of well-being, mental state, attention level, and atmosphere appraisal via a full-size mock-up experiment fitted with LEDs. In terms of measuring techniques, the PANAS scale was used to measure emotional changes, which was interpreted as well-being in this study. Their result suggested that subjects reported higher positive affect, performance activity, and general well-being under the 5000K lit environment than the 4200K lit environment although there was no statistically significant difference in perception of atmosphere appraisal between the two different CCT levels.

Their result is particularly interesting to the author as it somehow contradicts the findings from the previous review of Veitch *et al.*’s (1997) result. It could be summarised that differences between 4200K and 5000K (Denk *et al.*’s study) caused a difference in positive affect of subjects whereas a difference between 3000K and 4200K (Veitch *et al.*’s study) did not cause such changes even though the measuring tool was the same. Why and what caused such difference? First, it could be due to different experimental set-up. Veitch *et al.*’s experiment was set as a mock-up office whereas Denk *et al.’*s study set as a mock-up shop. Second, it could be hypothesised that human emotion is affected by the difference between 5000K and 4200K but not influenced by the difference between 3000K and 4200K. Additionally, using different light sources (LEDs vs. fluorescent lamp) could be a reason for difference in their findings. Lastly, different exposure time used in their experiment might have caused such different result. In fact, in Veitch *et al.*’s experiment, participants were exposed to one lit environment for 50 minutes whereas in Denk *et al.*’s study, subjects were exposed for only 11 minutes. Such a difference in exposure time might have caused these variations.

By reviewing the use of the PANAS scale in more recent lighting studies, it seems still uncertain whether there could be a general recommendation drawn from them on how to use up-to-date LEDs concerned with increasing positive affect in our emotional experiences, especially in indoor environments. However, it is noticed that emotional impacts of lighting on human has been reported especially via using a scale of a single measure of ‘sleepy-awake’ or ‘sleepy-alert’. One hypothesis from the above findings is that changes in horizontal illuminance level on a working plane or CCT values of light sources is likely to lead only a change of human emotion of ‘alertness-sleepiness’. With this hypothesis, it could be explained that why many lighting studies in this matter has often reported inconsistent results with the PANAS scale over and over. The PANAS scale would be an ideal tool to use if the human emotion of Positive Affect (PA) or Negative Affect (NA) was influenced by a particular variable. However, if human emotion which neither related to positive or negative feelings is involved – an example would be ‘alertness/sleepiness’ – then an alternative to the PANAS scale would be preferable.

Based on the review, the author feels that having a specifically developed research design is particularly important in lighting and emotion studies. First, if daylighting is included in a field study as an uncontrolled variable, the effects of spectral power distribution (SPD), CCT, illuminance levels or even different lighting systems (LEDs or fluorescent lamps) on emotional responses seems to become more immeasurable. Second, asking for responses a number of psychological variables, which has led participants to be exposed at a single light setting for 5 to 6 hours seem to be inefficient to extract the specific effects of affect or emotion. Alternatively, the problem could lie in the use of the PANAS scale, itself. It might be an inefficient tool to measure emotional responses, especially in lighting studies, which is supported by the fact that, as discussed earlier, some investigators acquired different results when they changed the measuring tool from the PANAS scale to a different set of questionnaires. Therefore, in the next section, this study discusses some of the lighting studies with the circumplex model of affect or similar concepts.

2.3.3 The circumplex model of affect

In Küller and Wetterberg’s experiment (1994), it is mentioned that they recorded participants’ affective states via a set of questionnaires that consists of 36 bipolar seven-grade scales based on the Mehrabian and Russell’s emotional model (1974). Although it sounds like either the PAD or the circumplex model of affect, there is no written part explaining this process. More surprisingly, their result suggested that there was no statistically significant difference in the measured affective state of their participants under four different light settings (3000K, 5500K, 500 lux and 1500 lux) even though it was measured twice in a day, 10:30 a.m. and 04:00 p.m. according to their experiment schedule. The only conclusion in this area was that participants felt more social, more negative and more bored during a shift over the day. Although their first part of emotion results was difficult to interpret, the later part has been particularly interesting to the author as it might suggest what emotional affective states are required at a typical office environment over a time shift from morning to the noon. This result seems to be credible as their experiment daily routine, which started 08:30 a.m. and ended 05:00 p.m. was very similar to many of typical office work hours. According to their finding, it could be assumed that changes in horizontal illuminances (500 lux, 1500 lux) and CCTs (3000K, 5500K) did not have an impact on human emotion on the circumplex model of affect. The author, however, concerns that whether it there is a need of a questionnaire that consists more than 35 bipolar adjectives to describe occupants’ feelings of the surrounding illumination.

Boyce *et al.* (2006) have conducted a series of experiments to investigate the effects of lighting and its control on human psychological experiences. Participants’ mood in their experiment was measured by a three-factor mood scale. This scale consists of the 18 semantic differential items, of which six each are averaged to form scores for pleasure, arousal and dominance (PAD) with a 9-rating scale (Russell and Mehrabian, 1974). Their results suggested that emotion is significantly associated with the time of the day. Pleasure level, for instance, dropping significantly from morning to afternoon along with arousal level dropped slightly less significantly at the same time shift. In the meantime, level of dominance was influenced by neither different light settings nor time of the day. Veitch *et al.* (2008) further calculated the results of other dependent variables such as lighting appraisal, preference and environmental satisfaction and attempted to link with each other as a form of linked mechanisms, which later concluded as ‘Appraisal path’, which is to be discussed later in this chapter.

Kim and Mansfield (2016) studied two café users’ psychological experiences, one of which was daylit and the other one non-daylit. In their field study, users’ emotion was measured by the affect grid. They reported that a significant difference in perceived emotion, which was dependent on the presence of daylight but also cultural difference. Although their study also reported interrelationships among other psychological variables, as far as emotion was concerned, the affect grid was an effective tool that also detected gender effect (in an unpublished study).

Lastly, there is an interesting series of experiments from the Netherland that investigated the effects of lighting on both atmosphere perceptions and affect states with consideration of age differences. In their first experiment, Kuijsters *et al.* (2014) created four different living room light settings with the help of lighting designers with up-to-date Philips LED installations although the process of the lighting designers’ involvement was not stated in their publications. As their experiment was set up at the Philips experience lab, the author suspected that lighting designers were involved at the construction stage of the lab. They classified the four settings as ‘cosy’, ‘relaxing’, ‘activating’ and ‘exciting’ and recruited two groups of participants, young and old groups, and asked the groups to rate their perceptions of atmosphere and affect states separately. In their study, perceived atmosphere was measured by a simplified version of Vogels’ questionnaire (2008), which was reviewed earlier this chapter. Affect states of the participants were measured by a questionnaire developed by Russell (1980), which indicates that their study adopts the theory of the circumplex model of affect. Their version of the questionnaire consists of 20 adjectives with 8 rating scales (10 for pleasure/displeasure scale, and the other 10 for activation/deactivation scale). Unfortunately, their aim was rather close to investigate what atmosphere perceptions were generated by the four different light settings than measuring the influenced affect states and match them on the circumplex model. The author suspects that it was due to the names of four perceptual dimensions defined by Vogels (2008). As reviewed earlier, Vogels named the four dimensions of atmosphere as cosiness, liveliness, tenseness and detachment, which are very similar to the names of four light settings created.

They concluded in the main two things. First, the younger group of participants were more sensitive in perceived atmosphere appearances. Therefore, they further reinforced their light settings for the elder participants and consequence achieved similar level of sensitivity in perceived atmosphere appearances. Their 'cosy' light setting evoked high value in cosiness and low values in liveliness, tenseness and detachment of atmosphere perceptions. Their 'activating' setting evoked high values in liveliness and detachment whereas low values in the other two perceptions. The only difference between 'exciting' and 'activating' setting was that 'exciting' setting led participants to perceive low level of detachment. The 'relaxing' setting has resulted low values in all of the dimensions.

Kuijsters *et al.* (2015) also conducted another experiment using the same light settings but only 'activating' and 'cozy' setting were adopted this time as those two, in their opinion, are the key settings in enhancing perceived lighting quality. Their aim was to test whether such settings could transform elder people's negative emotion into a positive emotion. Unlike the previous study, they did not measure the atmosphere perceptions and instead measured affect state via a self-reported scale of pleasure and activation level as well as several other physiological variables such as electrocardiography (ECG), and skin conductance response (SCR).

Their research process started by first inducing two negative emotion states, anxious (defined as low pleasure and high activation) and sad (low pleasure and low activation based on the circumplex model of affect) to the elder participants by showing a short clip of two films, 'the silence of the lambs' and 'the champ'. Then, after the watching the clops, the participants reported their affect states every 2 minutes for five times under three different light settings, 'activating', 'cozy' and 'neutral'.

Their result suggested that both the subjective and physiological responses showed that negative emotions were successfully induced although unexpectedly the participants felt low pleasure and high arousal after watching the sad film. As a result, the participants under the cozy lighting setting reported significantly higher pleasure rating and significantly lower activation level than the subjects under the neutral light setting. Such a result was also backed by the related physiological responses. However, the participants under the activating light setting was found to be physiologically activated although there was no significance found on the self-reported level of activation compare to the case under the neutral light setting.

In summary, an extensive review on lighting studies on human emotion based on the PANAS model was conducted and written in Chapter 2.3.2 and a literature review on lighting studies on human emotion based on the Circumplex Model of Affect was explained in Chapter 2.3.3. Before the thesis compares pros and cons of using each emotion model in lighting studies, this chapter now discusses which factor of lighting quality to be focused on by this study between ‘visually appealing perception of a space’ and ‘positive emotion (mood)’.

2.3.4 Perception of space vs. Moods

Earlier, this chapter has defined two key requirements that would bridge the gap between indifferent quality and good quality of lighting at a workspace: one is ‘visually appealing perception of a space’ and another is providing ‘positive moods (affect)’ to its users. By having reviewed both aspects of human psychological responses have led the author to contemplate which one to put more weight on.

First, many would agree that we are no longer in desperate need for enhancing level of brightness at least regarding functionality in most of indoor workspaces. Therefore, weighting more on other perception of a space such as attractiveness and visual comfort from a design stage would make sense in bridging the gap. However, this study would like to point out a theoretical concern in this matter obtained from the literature review on human perceptions of a space and lighting environment.

There seems to be no general agreement in the found factors of human perceived appearance of a space. For example, Flynn *et al.* (1973) extracted five factors of human subjective perception of a space, named as ‘evaluative’, ‘perceptual clarity’, ‘spaciousness’, ‘formality’ and ‘spatial complexity’ of which the first three were statistically strong. Loe *et al.* (1994) found two factors and named them as ‘visual interest’ and ‘visual lightness’. Veitch and Newsham (1998) extracted three factors that were ‘complexity’, ‘visual attraction’ and ‘brightness’. Having no widely-accepted factors of the perception means that no specific objective would be given in a design stage. Moreover, the found factors accounted for approximately 40% of the whole variance. In other words, our current understanding in dimensions of visual perception of environment (either room or lit environment) are still uncertain and even when some dimensions were suggested, it would be likely to explain less than half of the human visual perceptions of a space. As Cuttle proposed, we could just let lighting designers to freely explore their skills and experiences to create better quality of lit environment as long as it meets the minimum perceived adequacy of illumination. However, this study concerns that such approach might not reflect the individual needs of space occupiers and rather be dependent on lighting designers’ own skills and professional experience to achieve improvement in lighting quality.

On the other hand, regarding human moods (emotion), there are widely accepted dimensions that construct emotion. Although the circumplex model and PANAS model slightly differ in their characters, *pleasantness* and *activation* are the widely agreed two dimensions that constructs affect models. However, it was also observed that lighting studies in this area have often shown inconsistent results. Would it be an inevitable nature or limitation? Perhaps. But also, there is a possibility that the measurement scales that are widely involved in lighting studies such PANAS scale were not particularly efficient in interpreting the impacts of lighting, especially at a workspace environment. The author’s impression is that although there seem to be a greater number of lighting studies, concerned with the PANAS mode (see Table 2.3), studies that referred to the circumplex affect shows less inconsistent results. The reason for that is, as stated earlier in this chapter, the PANAS model (with the PANAS scale) would be particularly useful if changes of lighting conditions influence participants’ emotion of either positive or negative feelings. However, many studies have suggested that changes in light conditions, especially horizontal illuminance levels or CCT levels have an impact on human emotion of ‘alertness-sleepiness’ only. Further, some adjectives in the PANAS scale such as ‘afraid’ or ‘proud’ do not seem to be suitable to investigate an impact of lighting stimuli on human emotion.

Potentially, light and lighting as a stimulus to human emotion or moods could be different in its characters such as stimulus intensity from other stimuli that are associated with psychological, medical and clinical studies and such differences may have caused the inconsistent results.

However, PANAS scale and the circumplex model of affect are regarded as two well-established concepts of human emotion and have been validated its structure and functions in many areas of studies including non-clinical studies (Crawford and Henry, 2004; Terry *et al.*, 2003; Watson and Clark, 1997; Watson and Clark, 1999; Thompson, 2007).

In the beginning of this chapter, the study argues that the most of current lighting installations at a workspace environment would provide between indifferent and good quality of perception to its occupants. Therefore, it would be logical to assume that occupants’ feeling or moods that are induced by lighting is in also between a neutral to slight positive state. The question is whether using of measures of two dimensions of emotion (*pleasantness* and *activation* for the circumplex model of affect and *positive affect* and *negative affect* for the PANAS) solely to be effective to distinguish the subtle difference. This study starts from questioning the above statements and expands the idea to further analyse a potential of human emotion as both a lighting design objective and lighting quality assessment.

Table 2.3. Reviewed lighting studies that are associated with the PANAS model, and the Circumplex model of Affect

The PANAS model	• Baron *et al.* (1992) • Knez (1995a; 1995b) • Knez & Kers (2000), Kenze & Hygge (2002) • McCloughan *et al.* (1999) • Veitch *et al.* (1991) • Veitch (1997) • Plitnick *et al.* (2010) • Figueiro *et al.* (2011) • Denk *et al.* (2015)
The Circumplex model of Affect	• Kuller and Wetterberg (1994) • Boyce *et al.* (2006) • Kim and Mansfield (2016) • Kujisters *et al.* (2014; 2015)

2.4 Potential of emotion-based lighting design

One characteristic that both the circumplex model of affect and PANAS model shows is that they shared their concepts in their model structure that human emotion is well explained by two-dimensional circumplex space. Further, it is argued that the PANAS model is a rotational variant of pleasure-displeasure and activation-deactivation structure, defining the circumplex with dimensions at a 45º rotation to the activation and pleasantness dimensions (Barrett, 1995; Barrett and Russell, 1999). Figure 2.14 shows the two emotion models, the PANAS model and the circumplex model within a two-dimensional circumplex space.

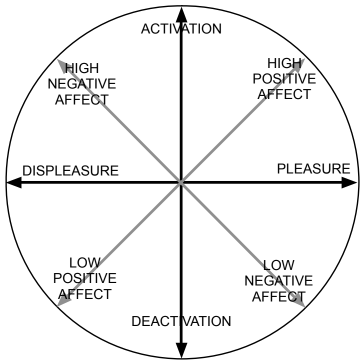


Figure 2.14. Two models of emotion within a two-dimensional circumplex space (Adapted from Barrett and Russell, (1999))

This study, then, hypothesized that level of pleasantness is related with perceived lighting qualities. For example, it could be assumed that bad quality of lighting would result in unpleasantness whereas good quality of lighting would lead to an increase in pleasantness. Such hypothesis was built on the earlier findings suggested from literature review in Chapter 2.2 and Chapter 2.3. Such hypothesis was then graphically presented on two emotion models, the circumplex model of affect and the PANAS model as shown in Figure 2.15. As argued by Boyce (2013a), most of lighting quality perceived under modern workspace environments are hypothesized between indifferent and good quality, which is highlighted in Figure 2.15. Although two emotion models show the same graphical description of lighting quality (rotation by 45º), representation on the circumplex model provides a more of visually clear interpretation than the PANAS model and the terminologies of ‘positive affect’ and ‘negative affect’ is more unfamiliar than the parameters from the circumplex model of affect.

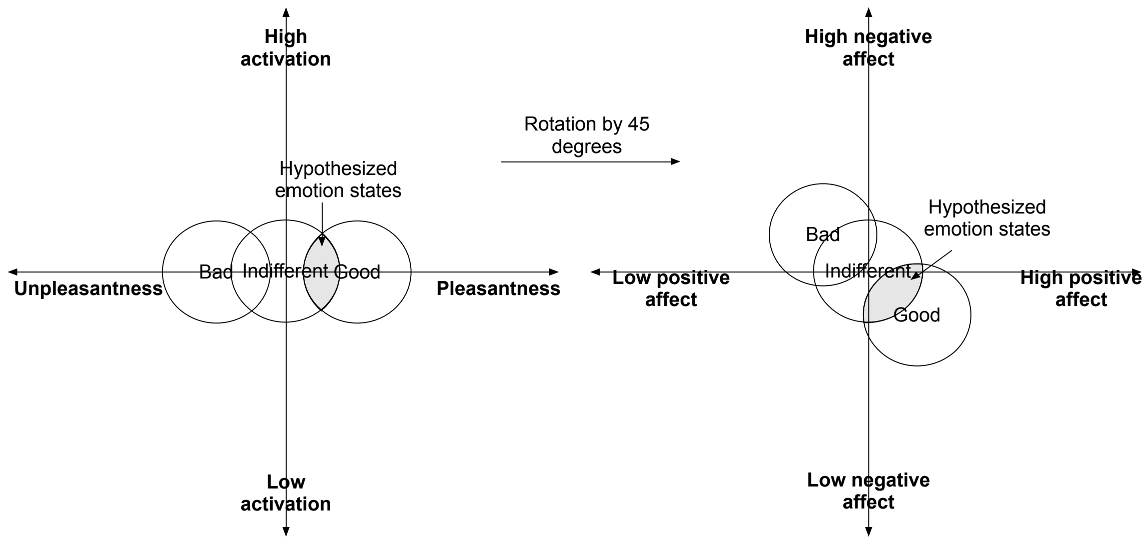


Figure 2.15. Hypothesized Boyce (2013)'s concept of lighting quality on two emotion models
Note: left figure shows classification of lighting quality on the circumplex model of affect and the right figure shows lighting quality classifications on the PANAS model.

Once the link between lighting quality and the emotion model was set and presented, it was clear that an improvement in lighting quality would result in three potential emotional changes, which are represented as A, B and C in Figure 2.16. Emotion 'A' takes place in a situation where an occupant feel both high pleasantness and with high activation than the hypothesized emotion state. Emotion 'B' shows an increase in pleasantness and Emotion 'C' indicates a situation where a user feel more pleasant and with low activation level.

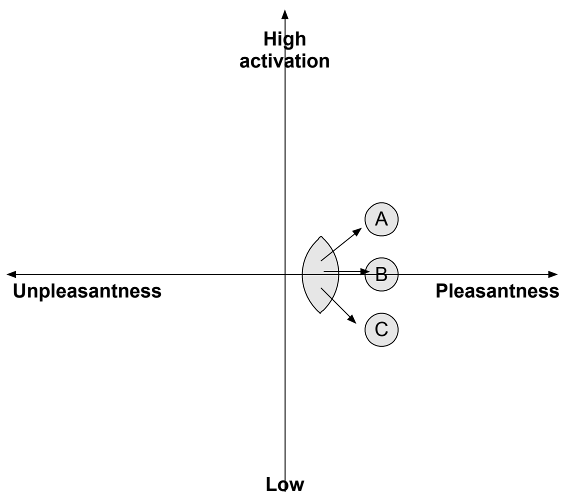


Figure 2.16. An improvement in lighting quality expressed in three potential changes in emotion

In short, if a lighting design approach could lead to one of the above three situations, it would mean an improvement in lighting quality beyond the indifferent level. Regarding the effects of lighting on human activation (alertness or arousal) level, a large body of research has been conducted. Most of these studies investigated effects of light intensity under conditions of relatively high fatigue and sleep pressure. Several laboratory studies have, for example, demonstrated that exposure to higher illuminance levels at night resulted in lower levels of melatonin secretion, increased physiological arousal, and higher subjective alertness (Boyce *et al.,* 1997; Cajochen *et al.,* 2000; Badia *et al.,* 1991). Several studies also showed alerting effects of bright light during regular working hours. Smolders *et al.* (2012), for example, suggested that exposure to a higher illuminance at eye level induced subjective alertness and vitality as well as increasing physiological arousal level even in the absence of sleep and light-deprivation situation. The difficult part is how do we achieve A, B or C of emotions by a different sets of lighting arrangements?

In summary, this chapter categorised two main psychological responses to lighting, ‘visual perception of a space’ and ‘emotion. An in-depth literature review on ‘visual perception of a space’ was followed and the result suggests that although several studies have successfully explored an impact of lighting on human perception of a space and as well as even suggested lighting design indicators in this matter, our knowledge on how to achieve a visually appealing perception of a space seems still largely uncertain due to a lack of fundamental knowledge on what constructs human perception of a space. On the other hand, a literature review on two emotion models, the Circumplex Model of Affect and the PANAS suggests that positive moods (or emotion) can clearly be defined although how to achieve it is also a challenging subject. Table 2.4 summarises a comparison of attribute of PANAS and Circumplex Model of Affect. As can be seen from below table, the PANAS model benefits from the presence of PANAS scale, which allows researchers easily explore, investigate and compare the size of an impact from lighting changes on human emotion. However, it has also disadvantages that first if human neutral feelings (e.g., subjective alertness, sleepiness) are strongly stimulated by changes in lighting conditions, it could provide inaccurate results. Second, although the PANAS scale has been widely used in many different areas of studies, it seems not the most appropriate tool to investigate an impact of lighting. Therefore, this study has adopted the Circumplex Model of Affect as a theoretical basis to explore an impact of dynamic light settings on human emotion.

Table 2.4. A comparison of the attributes of the PANAS and the Circumplex Model of Affect

	Attributes of the two emotion models
The PANAS model	• Defines human emotion with two following orthogonal dimensions; *'High Positive Affect (PA) vs. Low PA'* and *'High Negative Affect (NA) vs. Low NA'*. • The model has been adopted by many of different areas of studies including both clinical and non-clinical studies. • Although the model presents a theoretical structure of human emotion, there is a set of questionnaire that allows researchers practically explore the model, called the PANAS scale. • The PANAS scale consists of 20 adjectives and some of the adjectives such as 'proud' and 'afraid' do not seem to be most appropriate in investigating an impact of lighting on human emotion. • The PANAS scale provides numerical scores of both PA and NA, which enables researchers to easily compare the size of the effects over time or so on. • Relating to the earlier point, the PANAS scale only measures an impact on human emotion of PA and NA. Therefore, an impact on subjective alertness or sleepiness cannot be identified.
The Circumplex Model of Affect	• Defines human emotion with two following orthogonal dimensions; *'Pleasure vs. Displeasure'* and *'Activation vs. Sleepiness'*. • The model has been verified by many of different areas of studies including both clinical and non-clinical studies. • Unlike the PANAS model there is no defined set of questionnaire that allows researchers to practically explore the model. • Therefore, researchers who wish to explore an impact of human emotion based on this model are encouraged to use either the 'Affect Grid' or a modified list of adjectives to match their research interests. • Unlike the PANAS model, an impact on subjective level of alertness or subjective level of pleasure can be explored.

Chapter 3

Research Methods

The previous chapter discussed the usefulness of the Circumplex model of affect, as a theoretical basis to explore and investigate an impact of dynamic lighting settings on human emotion. In order for such exploration and investigation, the thesis comprised a detailed research programme, consisting of two separate phases. The first phase aimed to explore emotion-based lighting design practice, and in the second phase, an investigation of human emotional experiences was conducted under controlled lighting settings which were set up based on the results of the first phase.

3.1 Research design for emotion-based lighting design

The focuses of the first phase of the detailed research programme are (1) to explore a set of dynamic lighting arrangements in the workspace that leads to positive emotions, and (2) to identify the elements of lighting design or luminous conditions which are associated with human emotion.

3.1.1 Two emotion states: ‘lively’ and relaxing’

First, this study defined two emotion states; ‘lively’ and ‘relaxing’ as the targets of the emotion-based lighting design practice. These affect states were not randomly defined but were built based on two theoretical emotion models.

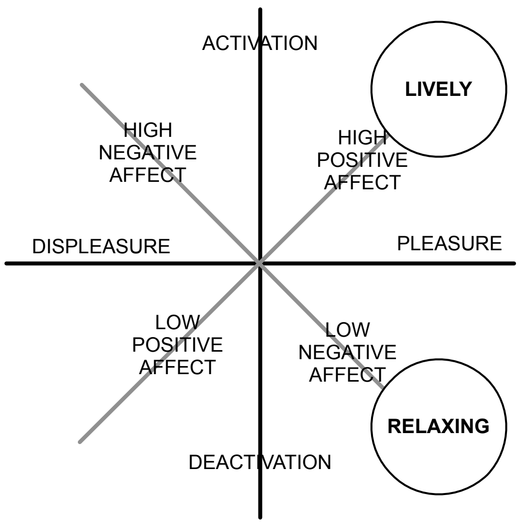


Figure 3.1. Emotion states of ‘lively’ and ‘relaxing’

Figure 3.1 shows mapping of these two affect states on two different emotion models, the circumplex model of affect and the PANAS model, which were extensively discussed in previous chapter. As shown in Figure 3.1, ‘lively’ is a state of affect that could be described as ‘pleasing and with high arousal’ and ‘relaxing’ is a state of affect which is ‘pleasing and with low arousal’ according to the circumplex model of affect. In PANAS term, ‘lively’ is the same affect state as ‘highly perceived Positive Affect (PA)’ and ‘relaxing’ is ‘low level of Negative Affect (NA)’.

3.1.2 Participating lighting designers

After defining the ‘good quality (target) of emotion states’ from workspace. The study then focused on a specific research design on how to explore ‘lively’ and ‘relaxing’ workspace. A ‘lively’ workspace in this study means that users of the space feel both pleasant and highly activated through the surrounding luminous condition while performing their work tasks as well as a perceiving satisfactory level of visual comfort and appearance. On the other hand, a ‘relaxing’ workspace means that users feel both pleasant and calm or quiet while also perceiving good qualities of other indoor environmental factors.

An obvious approach would be identifying potential ‘lighting design elements’ that are associated with the positive emotions and to characterise them so they could be replicated and tested in the real environment. This study, however, claims that there is a lack of formal attempt on establishing a relationship between ‘lighting design elements’ and human emotion and thus has chosen to gather ideas of such design elements from experienced lighting designers. As a result, five experienced lighting designers were invited to devise two sets of lighting design concepts, one ‘lively’ and one ‘relaxing’.

The lighting designers were not randomly chosen or recruited. Selecting the lighting designers was an important part of the field study as all lighting designers have their own styles or preferences while working on their projects, which is possibly due to their differences in educational/practical backgrounds or years of experience. Moreover, differences in cultural backgrounds are also believed to be an influencing factor in their final designs. Although the author welcomes the differences in their ways of exploring design thoughts on two different workspaces, there are several factors that this study had considered as essential elements from the designers.

First, the lighting designers who participated in this phase of the study should be well-aware of smart lighting technologies and have some amount of experience in designing various workspaces. Second, the targeted lighting designers were desired to have a certain level of lighting/architecture/interior background whether in education or practice, so they are confident in playing with a limited range of interior finishes and light equipment to create workspaces that are perceived to be both visually appealing and emotionally-rich. Lastly, London-based or lighting designers who have sufficient experience in England were preferred to minimise the risk of cultural preferences in interior designs but also due to the geographical limitation. This study did not want the lighting designers to participate this phase without a visit to the actual target space where they could see and play with all of the interior materials and light equipment before their design exploration.

Based on the above criteria, ten lighting designers were initially selected and contacted in April 2015. Seven out of the ten designers verbally agreed to come to the school to get to know more about their possible participation of this study. Between May and July 2015, seven lighting designers came to the school to be briefed on the study participation. After the design brief, five designers consisting of three males and two females confirmed that they were confident and highly willing to explore emotion-based lighting design for workspaces. As a result, five London-based intermediate-to-senior lighting designers who have had between three to six years of practical experience agreed to take part in this phase of the field study. One particularly encouraging feature was that all of them are in their late 20’s or 30’s and were relatively well-aware of smart lighting equipment. All of them expressed their excitement to design a workspace with such lighting equipment, as most of their current/past projects have not involved such usage. The full document of agreement is attached as Appendix 1. The details of design brief context are further discussed in Chapter 3.1.3.

3.1.3 Target space and materials

After the consent to the participation, the next step for the author was to prepare a target space and some light equipment. The space and light materials must have represented some of the most up-to-date light technologies while providing an easy access to both author and the lighting designers. This study has received a generous research funding from SUKWOO Eng. in South Korea to support this stage. The details of the Gift Agreement are explained in a Memorandum of Understanding between SUKWOO Eng. and UCL, which is attached as Appendix 2.

The initial consideration was how much flexibility should be given to the participating lighting designers. In terms of the flexibility, the main considerations have lied on three following factors:

1) Characteristics of the space
2) Layout of workspace furniture
3) A range of light equipment and materials that can be used for their concepts

Ideally, the lighting designers could have explored and articulated their ideas on ‘lively’ and ‘relaxing’ workspace lit environments most efficiently if there was no restriction in any of design elements. However, that is not the way that lighting practice works in the real world and one goal of this phase was to develop the luminous conditions to be used for the experimental study. Therefore, this study has restricted the characteristics of space and a range of lighting equipment and materials.

A conference room (4.2m×8m×3m) that is located on the first floor of the Bartlett School of Environment, Energy and Resources (BSEER), Central House, was chosen for the target space of the design concept. Central House is a part of the estate of UCL and the exact address of the building is as follows:

- Central House, 14 Upper Woburn Place, London, WC1H 0NN.

The conference room was chosen as a target space for having two reasons. First, the room is already equipped with eight recessed ceiling luminaires, ChromaWhite^{TM}, programmable and colour-tunable LEDs which is developed by Photonstar Ltd. as shown in Figure 3.2(a) and Figure 3.3 (for floorplan). ChromaWhite^{TM} delivers tunable white light, from 2,700K to 6,500K with a value that does not drop below R_a=90 across the range according to the product specification. The control of colour and intensity tuning could be achieved by both the circuit on the manual luminaires control panel and programmably via a connected computer on the same Wi-Fi. (See more information at http://chromawhiteled.com/technology/chromawhite_2.0) Two photos of the conference room illuminated by ChromaWhite^{TM} at 2,700K and 6,500K are presented in Figure 3.4 for clear understanding of the space and the effects of colour tunable function by the recessed ceiling luminaires. Second, as shown in Figure 3.4, this room is pre-installed with a room divider that allow participants come and go to a waiting area while the light settings are being changed.

(a) Photonstar Chromawhite^{TM}

(b) Philips Hue light strip

(c) Philips Hue A19 lamps

(d) Philips Hue Gu10 lamps

Figure 3.2. Four light sources used in the design concepts

Based on the above advantages, the conference room was set as a target space for the design concepts. In terms of interior finish and furniture layout, although the space is originally a conference room, the designers were told to freely modify the room furniture layout from scratch as long as their suggestion was reasonably accessible.

Regarding the selection of materials, the most considered factor was to provide a good example of recent connected lighting equipment as well as contemporary interior materials so that the designers could put them in an architectural context as much as possible. As a result, three light sources were selected and included in the design brief document, (a) Philips Hue A19 lamps, (b) Philips Hue GU10 lamps and (c) Philips Hue LED lightstrips as shown in Figure 3.2. All of these three light sources are colour-tuneable LEDs with a wide range of colours both saturated and white. They support 'smart control' via a computer or any smart device. (See more information at http://www2.meethue.com/en-us/products/). Details of the range of colour tunability was included in the design brief document (Appendix 3). By 'smart control', the designers were informed that they could include light settings such as varying intensity or colours over time.

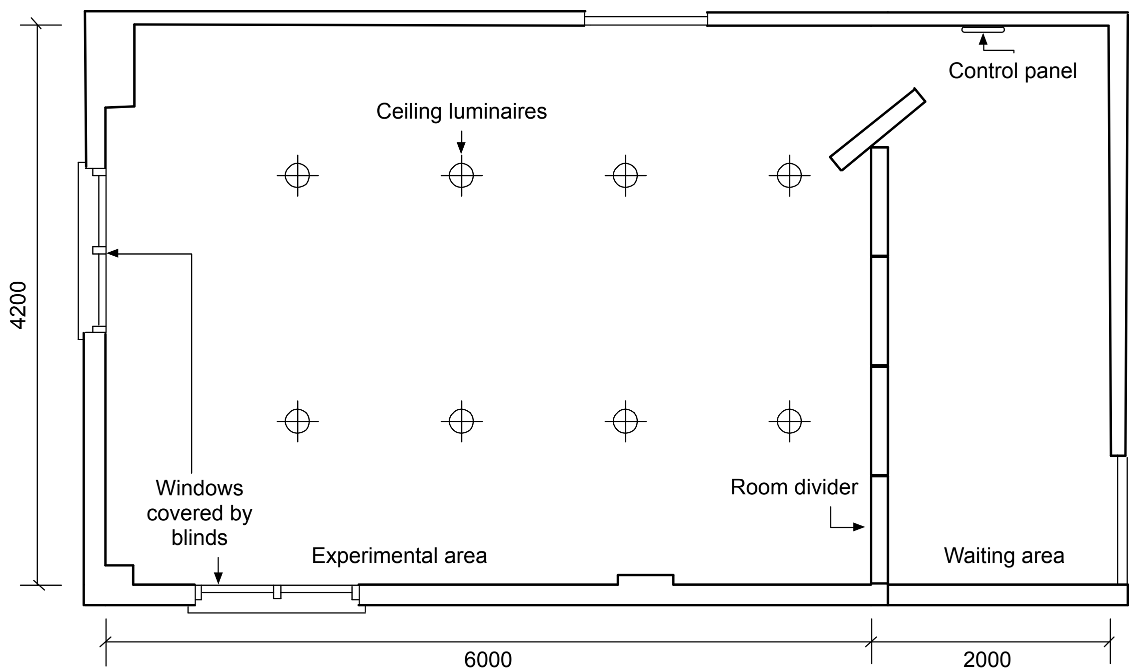


Figure 3.3. A floor plan of the conference room
(Eight recessed ceiling luminaires are displayed in the plan)

There was no limit to the numbers of lamps or lightstrips in the design concepts as well as the application and mounting position. In other words, the lighting designers were able to suggest any form of lighting at any mounting position with the above light sources listed above. For example, pendant lighting, wall-washing lighting, table lamps, and wall-mounted lighting were all encouraged to be suggested without restriction in numbers or shapes or locations.

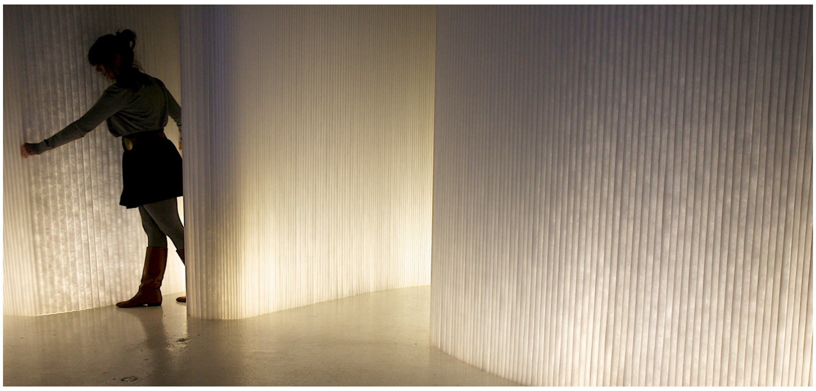
(a) The conference room illuminated by ChromaWhite™ (2,700K)

(b) The conference room illuminated by ChromaWhite™ (6,500K)

Figure 3.4. Two photographs of the conference room being illuminated by ChromaWhite™

Another material included as an option is a wall partition that takes a form of polyethylene volumes (4.5m×1.8m×0.2m), made by Molo®. This wall partition (called as 'softwall' by the manufacturer), which is made of white textile, could be transformed into a completely pliable, freestanding, glowing space partition as shown in Figure 3.5. Further, this wall could be integrated with the Philips LED lightstrips to turn the white textile modular partition into an interesting source of light. One growing trend that is being seen in contemporary interiors is the use of self-luminous partition/barriers to enclose and define architectural space (Papakammenou, 2012), whereas the conference room in this study is a plain rectangular shaped room, which lacks such architectural context. Therefore, including the softwall as an optional item gives lighting designers to ability to configure it in various curved ways within the space to enhance the architectural context.

(a) Application of the softwall (without lightstrips)



(b) Application of the softwall (with lightstrips)

Figure 3.5. Two applications of the softwall: a curved partition and a self-luminous light source (Images from the manufacturer 's website http://molostore.com/white-textile-softwall.html)

The presence of daylight was also an important factor when developing the research design. It is suggested that people in general prefer and reported higher well-being in spaces that make extensive use of daylight (Franta and Anstead (1994)), although some studies such as Veitch and

Newsham (2000) and Marwaee and Carter (2006) suggest that such behaviour of preference is not unconditional. Gou *et al.* (2015) suggests that people like natural light, provided that no associated discomfort such as glare or overheating disturbs their activities. With all respect to the potential and found benefits of having daylight in the workspace, it often causes a significant deviation between objective and subjective measures of psychological responses. For example, in Kaplan (1993)'s study, the workspace with a window and a view led a fewer report of ailments than a windowless workspace. Leather et al. (1998) also found that sunlight penetration had significant effects on job satisfaction, and general psychological well-being. These findings suggest that with the presence of daylight, it would be difficult to investigate an impact of dynamic lighting settings on human emotion. Therefore, this study excluded the presence of daylight and informed the participating lighting designers not to consider it as a design factor. This section, so far, has explained how the target space was set and what materials were prepared for the lighting designers to explore their design concepts. The main objective and requirements for the design concepts are explained in the next section.

3.1.4 Data collection and analysis technique

Once the space and materials were set, a design brief for each participating designer was conducted. The study briefings did not give them a strict deadline for the design development process. As a result, five design briefs took place in late June to early July 2015 and all of the design concepts were received by early September 2015.

During the design brief, the definition of 'lively' and 'relaxing' was explained to the designers both verbally and in a written document. The design brief document is attached as Appendix 3. It was also explained in the beginning of the design brief that this study hypothesizes the affect state of occupiers in the conference room as starting from a neutral level. Therefore, it could be summarised that the lighting designers' task was to suggest two workspace environments that increased users' pleasure and activation/deactivation level based on the neutral value of the empty room by exploration of their skills and knowledge by experience. As explained in Chapter 2, according to the Circumplex Model of Affect, a feeling of 'tiredness' is theoretically opposite to an emotion of 'activating' and a feeling of 'stressful' is an opposite to a feeling of 'relaxing'. Instead of explaining the theoretical aim of this study, the lighting designers were informed that the purpose of this study was to explore smart workspace lighting design, which could promote employees' wellbeing level who often suffer from either work tiredness ('activating' concept can be applied) or stress ('relaxing concept' can be applied).

This study also informed the designers that the main target of a possible client for this design concept was a small-sized start-up company (which often only consists of 5 to 10 people overall) rather than designing a small room as a part of large firm such as a bank or a manufacturing firm. Due to the contemporary trends of start-up firms, which are often described as based on 'sociable', 'non-formal', and 'non-conventional' spaces, the designers were informed not to restrict their design explorations by slavishly following the current guidance or recommendations on general office lighting as well as energy efficiency if necessary. This is due to a claim of this study that the current lighting recommendations or guidance of workspace has not been mainly developed to reflect human psychological experiences. By such an approach, this study also expected to obtain their unbiased ideas of integrating connected lighting technology into the workspace. During the design brief, this study strictly did not mention the previous literature on relevant studies such as the effects of lighting level or colour properties of light sources on human activation level in order to prevent the lighting designers having any stereotype in their approach.

Preferred formats of the design concepts were also mentioned at the end of each design brief. It was clearly mentioned that the concept should be in a format of clear visual material rather than a notional concept. More specifically, it was required that a hand-drawn sketch or a computer graphic generated image, which must specify mounting positions and directions of every light source as well as shape of light shades if used. Due to the explanation of the above objectives and requirements of the design concept, each design brief took approximately two hours in the empty conference room with all of prepared materials in front of them. The participating lighting designers therefore had opportunity to see and control all of the lighting equipment and material before preparing their design concept.

Once ten different design concepts were all received, the study first checked whether all of the design concepts meet the scope of this phase of the study, which was clearly stated in the design brief document. All of the designers have accomplished the required tasks, which were (1) to develop each of 'lively' and 'relaxing' workspace design concept, (2) to create design concepts on indoor office environment with no access of daylight (natural light), and (3) to corporate with the prepared list of light equipment as well as the target space. An in-depth description and analysis of their design concepts are exclusively explained in Chapter 4.

3.2 Research design for the controlled experiment

The conversion from the design concepts into light settings took place once the in-depth description and the analysis of the concepts had completed. After the conversion and measurements of photometric and colorimetric variables of each setting, the second phase of the research programme started. The focuses of the second phase of the study are (1) to investigate an impact of the emotion-based light settings on human psychological experiences via a controlled experiment, and (2) to investigate whether the current assessment tools used in lighting studies effectively explore human psychological responses to the dynamic luminous environments.

3.2.1 Independent variable and lighting control system

There are overall fifteen light settings, ten converted from the lighting design concepts, and additional five added by this study. The explanation of the additional five settings can be found in Chapter 4.4. Aside from the fifteen light settings, the controlled experiment did not include any further independent variable. In terms of experimental design, this study adopted the repeated measures design. Repeated measures is basically using the same participants for all of the experimental conditions (Field, 2011). In the repeated measures approach, each individual act as their own control, so variability does not depend upon individual differences (Boyce *et al.,* 2003). Another benefit of repeated measures is that it requires fewer participants than a between-groups experiment (Howitt and Cramer, 2011). Since there were fifteen defined light settings as an independent variable, the between-groups experiment was not a realistic option for this study as it would easily require more than 300 participants.

However, it is also argued that using the same participants for all conditions leads to difficulties counteracting problems of order effect. Results could therefore be affected due to boredom compromising concentration and reducing performance in reaction times and accuracy (Pan *et al.,* 1994; Bergh and Vrana, 1998). During the experiment, the order of presentation of the different lighting settings to each participant was varied to minimise any order effects. In order to ensure a complete randomized order, the Microsoft Excel function of RAND was run prior to every experiment started. The Excel RAND function generates a completely random real number between 0 and 1 (For more details see https://support.office.com/en-us/article/RAND-function-4cbfa695-8869-4788-8d90-021ea9f5be73 assessed at 10th Jan 2018). Once the fifteen random numbers between 0 and 1 were generated, the study allocated them with 15 different light settings and started a randomizing again. Although the above technique was a very simple process, the study is confident that the presenting order of the fifteen lighting settings were completely randomized.

Another important element that was associated with the fifteen light settings for the research design of the experiment was the lighting control system. As shown in Chapter 4 and Chapter 5, several settings involved the use of dynamic lighting features. More importantly, an interval between one setting and another one should not take too much time so as to keep participants on track.

As a result, two different lighting control systems were used during the experiment. One was used to control all of the smart lamps (pendant lights, LED strips, table lamps, and wall lighting) within the experimental area. Although there were many varieties of available programs in the market that enable the control of light intensity and colour aspects of Philips Hue lamps, many of them were found inappropriate for the purpose of lighting research as they lacked detail in controlling colour aspects of lamps. Synthe FX, the developer of Luminair 3 application, which is a DMX lighting control platform for stage, film, studio and architectural uses, provides most functionality such as creating scenes for the settings, setting up groups of lamps, with control over both CCT and RGB levels that were required for this study. (For more details see http://synthe-fx.com/products/luminair). What was more promising was that they responded to the request from the author to add programmable control over CCT and RGB in the smart lighting in a slow loop. As a result, this study adopted Luminair 3 as the lighting control platform for controlling Philips Hue lamps during the experiment. Figure 3.6 shows a screenshot of Luminair 3 used in this study.

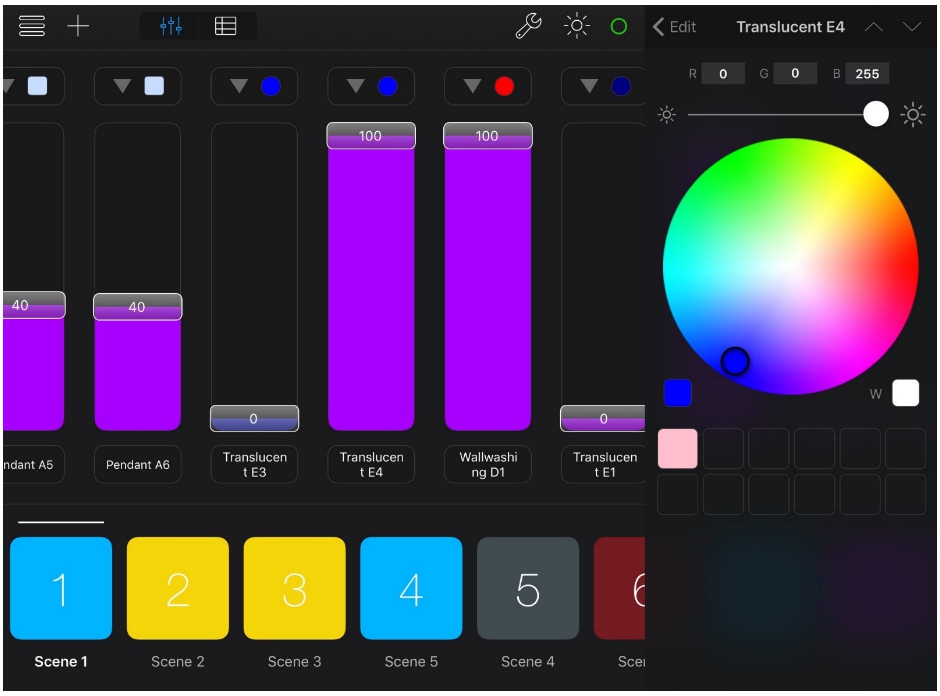


Figure 3.6. A screenshot of a lighting control programme (Luminair 3, developed by Synthe FX)

The control of the ceiling luminaires was adjusted by the installed control panel, which was mounted in the waiting area. Figure 3.7 shows a photograph of the control panel.

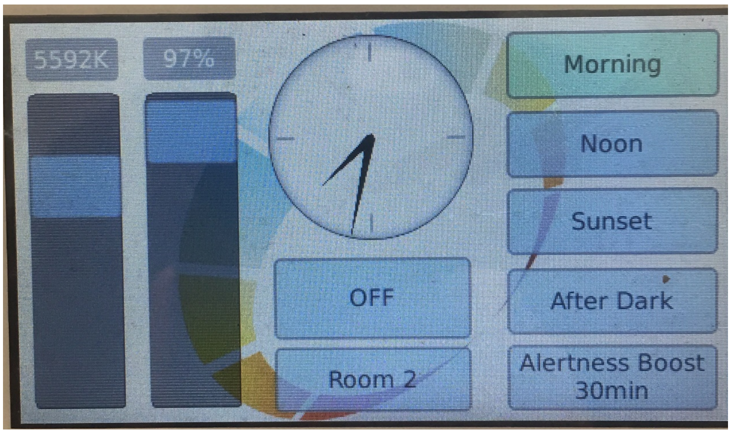


Figure 3.7. The control panel for the ceiling luminaire during the experiment

3.2.2 Visual task

This study did not include visual task performance as a dependent variable in the final experimental procedure. However, an explanation of why and how such an exclusion was made is needed to be explained before introducing the dependent variables that were actually used. Even though the aim of this study was not to investigate the impact of lighting on visual task performance it was felt important to incorporate a visual task in the experiment.

Therefore, the study originally considered a number of options for a suitable visual task. The types of visual tasks used in lighting studies vary from a simple typing test to a rather complex cognitive task. For example, a simple arithmetic/noun underlining test (which took approximately 2 minutes to complete) was adopted in several lighting studies (Boray *et al.,* 1989; Veitch et a*l.,* 1991). Regarding the complex cognitive task, a number of studies have asked their participants to read pre-selected articles and measured their abilities to summarise them or categorise them (Boyce *et al.,* 2006; Newsham *et al.,* 2004). Although such a method provides a situation that are like those encountered in daily life, the measurement is likely to take longer time (approximately 40 minutes) than the simple tests.

Based on the above literature, the study initially adopted a method of article reading in the pilot experiment. Participants in the pilot experiment, which was conducted between 4th June 2016 and 12th June 2016 were given ten minutes each to read one short article (300-350 words) and were given another five minutes to explain what they had just read to the author. Their performances were not measured as the presence of the defined visual task was mainly to reduce the uncontrolled element but also to provide a realistic workspace environment to the participants.

As a result, of the pilot test, it was decided to remove the defined visual task and allow participants to bring their own visual task and perform it during the experiment. More details of this part are explained later this chapter under the pilot study section.

3.2.3 Dependent variables

As discussed in Chapter 2, this study has argued that ‘visual perception of a space’ and ‘human emotion’ are two important factors in human psychological responses and therefore, a careful choosing of the dependent variables that represents the two factors was a very important step in this study.

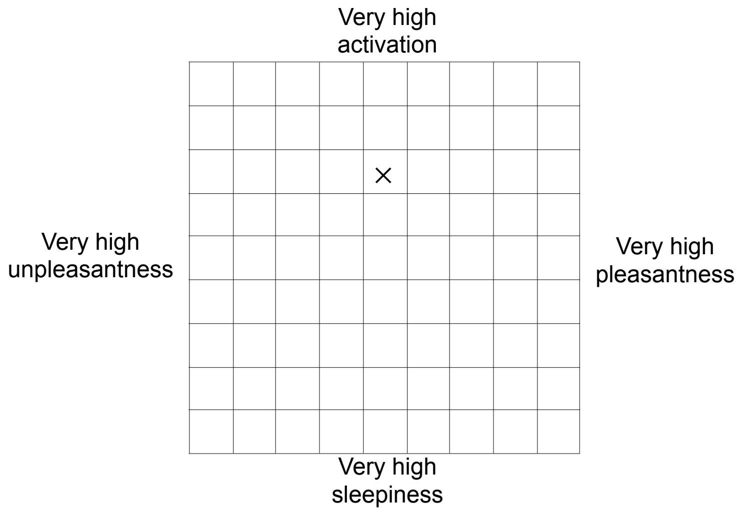
3.2.3.1 Emotion (affect)

Human emotion has been used as a dependent variable many times in lighting studies. This study has looked at the choices of how other lighting studies have measured human emotion in their studies in order to choose an appropriate one for this study. First, scales that are used by other lighting studies to measure human emotion of either ‘pleasantness’ or ‘sleepiness’ are summarised. There is a scale called Karolinska Sleepiness Scale (Akerstedt and Gillberg, 1990). This is often referred as the KSS scale by other studies. As the name of the scale suggests, it measures participants’ subjective feelings of sleepiness/fatigue/alertness. More specifically, participants are asked to place a mark on a 9-point scale rating how they sleepy they feel (1=’very alert’, 9=’very sleepy (fighting sleepy)’). Many lighting studies have used this scale in their studies. For example, subjective alertness improved under blue-enriched white light (17000K) (Mills *et al.,* 2007; Rautkylä *et al.,* 2010; Viola *et al.,* 2008).

There are other scales that allow researchers to measure both ‘pleasantness’ and ‘sleepiness’, too. Russell and Mehrabian’s semantic differential scale (Russell and Mehrabian, 1977, see Figure 3.8(a)) is an example. In their scale, there are 2 sets of 6 pairs to assess pleasure, and arousal (via 9-point scale). Pleasure, and arousal scores are the average of their sets. This scale has also been applied to many lighting studies such as Veitch *et al.* (1991), Veitch (1997), Hygge and Knez (2001), and Boyce *et al.* (2006).

There is also a scale that allow researchers to measure both ‘pleasantness’ and ‘arousal (or activation’ in a single way. The Affect Grid, which was first introduced in Figure 2.11 (Russell *et al.,* 1989), is an example of this. The Affect Grid is a single-item scale that is designed as a quick means of assessing affect along the dimensions of pleasure-displeasure and arousal-sleepiness, as for a reminder of this, the Grid is re-shown in Figure 3.8(b).

(a) Russell and Mehrabian’s semantic differential scale



(b) The Affect Grid

Figure 3.8. The Affect Grid and Russell and Mehrabian semantic differential scale.

In Figure 3.8, there is a mark 'X' on each scale, and this explains a way of how participants use these scales. In fact, the concept of the KSS scale is already included in both the Affect Grid and Russell & Mehrabian's semantic differential scale. Interestingly, all of the three scales that measures human emotion of 'pleasantness' and 'sleepiness' use a 9-point rating scale. There is also a set of questionnaire called the PANAS scale, which was heavily discussed in Chapter 2.3.2 and the study has already made its point clearly that the PANAS scale would not be appropriate to be used in this study.

This study as a result adopted to use the Affect Grid to measure subjective feelings of 'pleasantness-unpleasantness' and 'activation-sleepiness'. As claimed by this study in Chapter 2, the author believes that a relative short-term impact of lighting on human emotion would not require a series of adjectives to be described, especially by measuring its impact on a rating scale. For example, does a change of lighting condition for a half an hour in the workspace, really make people feel 'strongly more hopeful' on something or 'highly melancholic' in their emotion? Not many could confidently say yes. Further, what if people feel both slightly relaxed but also slightly excited because of a change of lighting? Is it really impossible? According to the Russell and Mehrabian's scale, it is impossible, as participants must make a choice either marking their feeling on a dimension of 'relaxed' or 'excited'.

The study therefore decided to give a selection of emotion adjectives for participants to freely choose of the closest ones of their feelings. In this way, they could choose both ‘relaxed’ and ‘excited’ if they felt that way.

Figure 3.9 shows the final twenty-four emotion adjectives that this study has selected to give a participant (all from the Circumplex Model of Affect) and bold letters in the figure indicate four theoretical zones of human emotion defined by two dimensions. Ten out the twenty-four descriptors are the ones that are also associated with Russell and Mehrabian’s semantic differential scales which are annoying, pleasing, dissatisfying, satisfying, boring, calm, sluggish, jittery and sleepy. Further, four adjectives were adopted from the PANAS scale, which were exciting, enthusiastic, activating, and jittery. These facts suggest that the selected emotion descriptors have been already used to measure our emotion intensities by many previous studies.

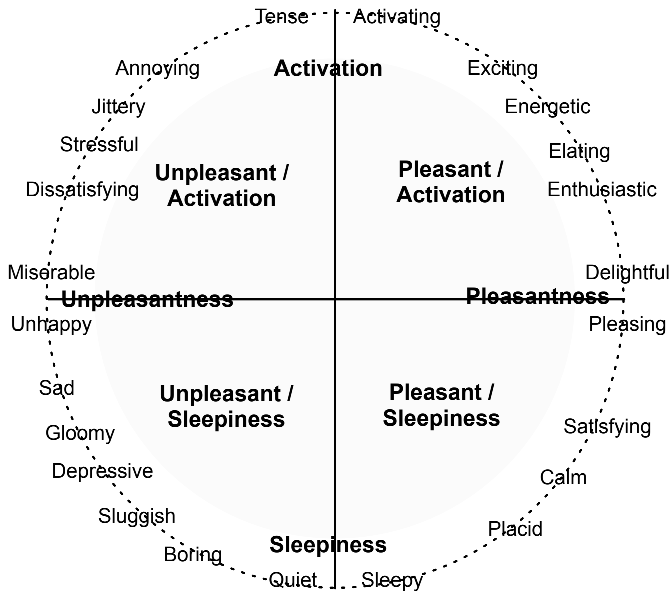


Figure 3.9. Twenty-four derived emotion descriptors from the circumplex model of affect **Bold** letters indicate four theoretical zones defined by two dimensions of human emotion

In order to measure frequencies rather than intensities of each feeling, the twenty-four descriptors were presented in a box and the study asked participants to choose the ones (possibly multiple ones) that described their feelings well. Figure 3.10 shows a cropped part of the emotion question from the questionnaire.

In this question, you are asked to assess your ***current feeling*** by putting a circle the adjective(s) in the below box that describe your *feelings most* closely. Multiple choices are allowed and if you wish to describe your impressions by using your own adjectives, please write down any additional words in the line below. Example sleepy

Tense	Delightful	Energetic	Miserable	Sleepy	Enthusiastic
Gloomy	Calm	Annoying	Placid	Jittery	Depressive
Quiet	Exciting	Pleasing	Sluggish	Satisfying	Sad
Activating	Elating	Stressful	Boring	Unhappy	Dissatisfying

Figure 3.10. Twenty four emotion descriptors (cropped from the actual questionnaire)

3.2.3.2 Appearance

Apart from human emotion, the study is also interested in 'visual perception of a space' of the fifteen light conditions. Six pairs of semantic differential scales (with 9 categories) were used to assess participants' perceived appearance of the room. Figure 3.11 shows the six SD scales used in the actual questionnaire. The study intentionally chose an uneven number of scale in this matter. Although having a neutral response in the scale might lead to a potential 'neutralisation' effect in the experiment, the study did not want to force the participants choose their perceived appearances by removing a neutral response. Additionally, the reason why the study used a 9-rating scale instead of a 7-rating scale or a 5-rating scale is that the study was confident that the designers' settings would evoke some extreme perceptions of the appearance.

Mark on the below scales how you feel about the ***appearance of the room***. For each pair, put a mark (see example) close to adjective which you believe to describe your feelings. The more one adjective describes your perceived appearance, the closer you should place your mark to it. Example

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	○	○	○	○	○	○	○	○	○	Dim
Uniform	○	○	○	○	○	○	○	○	○	Non-uniform
Uninteresting	○	○	○	○	○	○	○	○	○	Interesting
Chilly	○	○	○	○	○	○	○	○	○	Warm
Dramatic	○	○	○	○	○	○	○	○	○	Diffuse
Spacious	○	○	○	○	○	○	○	○	○	Confined

Figure 3.11. Six semantic differential scales on appearance of the room

Semantic differential scaling and paired comparisons are two of the common psychophysical methods used in lighting research, and have been used as complementary technique in the past. One common characteristic from previous lighting studies is that many of them have used more than 25 pairs of semantic differential scales (Flynn *et al.,* 1973; Veitch and Newsham, 2001; Boyce *et al.,* 2006; Loe *et al.,* 1994). It should be noted that their intention was to identify what constructs 'human perception of a space' in relation with several different lighting conditions. For example, in Loe *et al*. (1994)'s study, identifying a relationship between perceived appearances of a lit scene and various lighting patterns was the main research aim. However, as defined in Introduction, the main aim of this study is not quite identifying luminous elements that influences our perceived appearance of a space.

Further, many of the appearance descriptors (from the semantic differential scales) were found to be overlapped with the emotion descriptors. For example, 'pleasant/unpleasant', 'friendly/hostile', 'relaxed/tense', satisfying/frustrating', 'subdued/stimulating' and 'sombre/cheerful' were frequently associated with both uses of assessing emotion and assessing appearance of the room (Flynn *et al.,* 1973; 1979; Tiller and Houser, 2003; Tiller and Rea, 1992; Houser and Tiller, 2003). In this study, a questionnaire for measuring appearance of a room was developed with intention to avoid the overlapped variables and only include key factors of human visual perception of a space. Although, several studies have adopted a semantic rating scale range of a 7-rating scale, this study has a 9-point rating of semantic differential scales as the author was confident that a range of perceptions under the fifteen light settings would have a greater range than other previous studies.

3.2.3.3 Environmental satisfaction

Now, this study has chosen how to measure perceived appearance of a space and perceived emotion during the experiment. Theoretically, when people rate the space as being more attractive, they tend to report more pleasant mood according to the studies such as Boyce *et al.* (2006) and Veitch *et al.* (2008). However, such a path is not unconditional. Their findings suggested that such pathway only happens if people are satisfied about their surrounding lighting conditions and there is no light source that causes visual discomfort. In order to verify their findings, two variables, 'environmental satisfaction', and 'eyestrain' were added in this study.

Attractiveness of the space by lighting distribution and colour appearance were asked in the first two questions in environmental satisfaction of a room. Visual comfort and overall satisfaction level were also included as an item of environmental satisfaction. Lastly, the rendering quality of a person sitting next to each other (if none, then the author assumed the role during the experiment) was asked. Figure 3.12 shows a five-item questions (via a 5-Likert scale) that were used to measure environmental satisfaction. The questions regarding 'environmental satisfaction' were derived from several previous studies such as Sundstrom *et al.* (1994), and Boyce *et al.* (2006). They all used a 5-Likert scale to measure 'environmental satisfaction' and such technique has been verified by other studies such as Kim and Mansfield (2016).

Considering the lighting in this workspace, please rate ***lighting quality*** by placing a mark on the scales below.
Note that you are comparing this scene to the **default** scene when asked to assess the appearance.

Example ✓

	Not at all	A little	Moderately	Very much	Completely
Does the presence of the lighting make the space more attractive?	○	○	○	○	○
Does the colour appearance of the lightings make the room more attractive?	○	○	○	○	○
Overall, would you consider this workspace comfortably lit if you were staying for a few hours?	○	○	○	○	○
Overall, how satisfied are you with lighting in this space?	○	○	○	○	○
	Very poorly	Poorly	Acceptable	Well	Very well
Additionally, how does the lighting render the person sitting next you (for conference use)?	○	○	○	○	○

Figure 3.12. Five-item questionnaire for environmental satisfaction via a 5-point Likert scale (cropped from the actual questionnaire)

3.2.3.4 Eyestrain

A perception of eyestrain was measured in the experiment using a modification of the scale that has been used in many of previous lighting studies. The lighting studies such as Boyce *et al.* (2006), Newsham *et al.* (2004), Viola *et al.* (2008), and Galasiu & Veitch (2006) have used an 8-item questionnaire with 5 point Likert scale. The 8 items relating to subjective feelings of eyestrain were, smarting, itching, gritty feeling, aches, sensitivity to light, redness, tiredness, and dryness. In this study, four items (negative sensitivity to light, redness, eye tiredness, eye dryness) were asked to participants to self-analyse their symptoms of eyestrain by using a five-point Likert scale, ranging from ‘Not at all’ to ‘completely’. Such technique of the modification has already been applied and verified by other studies such as Kim and Mansfield (2016). Figure 3.13 shows a cropped version of the four-item questions that were used in this study.

Please move to the waiting area and wait for 10 seconds and rate your perceived *eyestrain* by placing a mark on the scale below.

Example

	Not at all	A little	Moderately	Very much	Completely
I am experiencing negative sensitivity to light from eye discomfort.	○	○	○	○	○
I am experiencing either of redness or soreness in the eyes	○	○	○	○	○
I am experiencing tired eyes.	○	○	○	○	○
I am experiencing dryness in the eyes.	○	○	○	○	○

Figure 3.13. Four-item questionnaire eyestrain (5-point Likert scale)

3.2.4 Participants

This section explains demographic characteristics of the participants in the controlled experiment. In total, 42 participants excluding the seven from the pilot experiment took part in the field study from 18th June 2016 to 28th August 2016. The 42 participants were consisted of 22 males and 20 females. Compare to previous studies such as Loe *et al.* (1994) which only involved 12 participants, this study considers having a number of 42 participants as an improvement. Prior to the main experiment, their gender, age, cultural background and educational background were asked in respective order. The case of visual impairment including colour vision was also analysed and tested with the Ishihara colour vision test before the experiment (online version of the test was used in this study, see http://www.color-blindness.com/ishihara-38-plates-cvd-test/ for a further detail). As a result, 15 out the 20 female participants had a design-related educational background and 12 out of 22 male participants had a design-related educational background. More details of participants’ educational background is shown in Figure 3.14.

Regarding the age distribution of the participants, 22 out of 42 were in their 20’s and 18 out of 42 were in their 30’s. There were only 2 participants who were in their 40’s (see Figure 3.15). Such a narrow distribution of age group was due to the fact that the recruitment process of the participants was mainly conducted from the Bartlett School of Environment, Energy and Resources (BSEER) and most of the participants were MSc degree students registered for 2015/2016 degree. All of them passed the colour vision and test although 20 out of 42 wore either glasses or contact lenses.

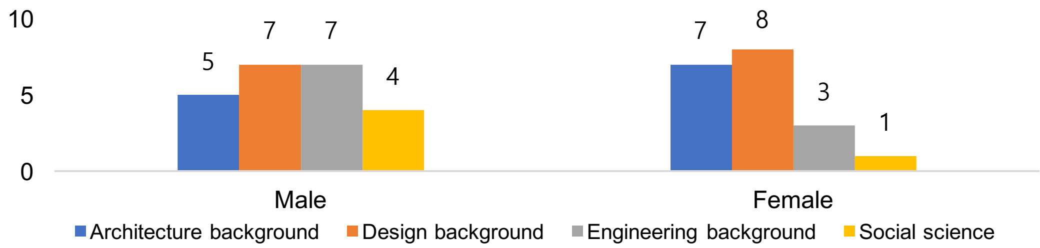


Figure 3.14. Educational backgrounds of the participants in the field study: phase II

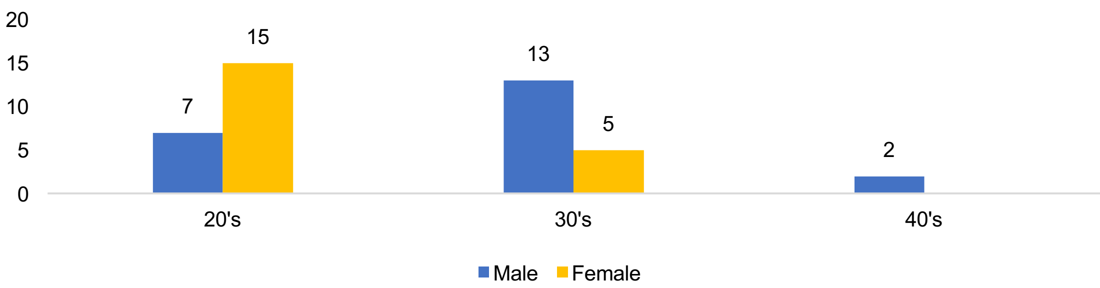


Figure 3.15. Age groups of the participants in the field study: phase II

Aside from the above demographic characteristics, the study also recorded three external variables. First, the time of the day when the experiment conducted was recorded. As a result, 24 out of 42 participants took part in the experiment that started 5:00 p.m. and for the rest of them the experiment started at approximately 1:00 p.m. Such differences in the start time of the experiment was unavoidable as the availability of the experimental space was limited during weekdays. However, during the weekend, the experimental room was fully available and this enabled 18 participants to take part in the experiment just after the 12:30 PM. Outdoor weather conditions were also recorded during the whole period of the experiment and the result shows that 36 out of 42 participants participated in the experiment in either clear or partly cloudy sky conditions, whereas the other 6 participated on a day with an overcast sky condition. Lastly, the case of whether participating alone or with an accompanying person was recorded. The study did not intend to restrict to a company, as it would provide a situation which felt more like a real workspace. As a result, 18 out of 42 participated as two participants together and 24 out of 42 participated in the experiment alone (there was no difference on the experimental procedure between one-person and two-person test). Although there were no defined group activities during the experiment, this study also did not restrict any form of social interaction between the participants.

3.2.5 Experimental procedure

The details of experimental procedure are explained in this section. Table 3.1 shows the list of activities undertaken during the experiment, in chronological order. As is clear from this list of activities, approximately an hour of preparation work was first carried out before a subject arrived at the experimental space. This mainly included installing several interiors and lighting fixtures such as pendant lighting, wall lighting, table lamps, a room divider and a curved partition. After this process, an empty conference room was converted into two separate spaces, an experimental area and a waiting area. For clear visual understanding, general views of the waiting area are shown in Figure 3.16. A general view of the experimental area was provided in Figure 3.16.

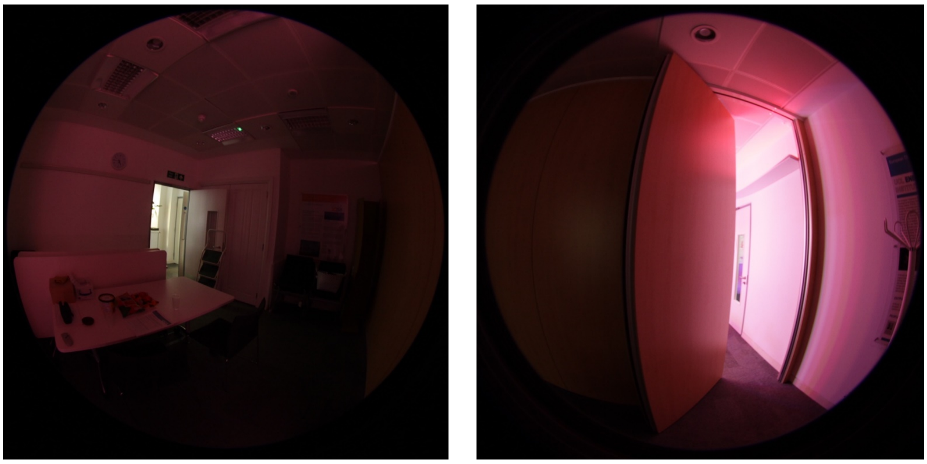


Figure 3.16. General views of the waiting area. Left photo shows the view from the door of the experimental area and right photo shows the view towards the experimental area.

Relatively low level of light (10 lx) on the horizontal task plane height was provided in the waiting area during the whole experiment for the purpose of adaptation.

A brief introduction to the experiment was provided just after the arrival of a subject. This included collecting demographic information from the participant as well as checking their visual impairments. Importantly, perceived thermal comfort was checked in this process with the maintained room temperature of 24^{o}C. Unless there was a request (no actual request was made) from the participants, the room temperature was evenly maintained throughout the experiment. As shown in Table 3.1, lighting condition during the introduction was defined as the ‘default’ setting by this study. Although it was named as a setting, there was no artificial changes of lighting condition

made under this setting. The default setting was the original lighting condition of the room without any amendment by this study.
Once the introduction and collecting the brief information had been carried out, a participant was asked to move into the waiting area for adaptation until they were called again. Once the first light setting was prepared, the author called the participants to move into the experimental area and this was the start of the first setting. Once the session started, the participants were given a 2-page questionnaire. Shortly after the questionnaire was given, participants were asked to report their *emotion* by choosing the selected emotion descriptors. After that, participants were asked to make judgements on the *appearance* of the room through six semantic differential scales (9-point scale), which was the end of first section of the questionnaire.

Participants were then asked to perform their *own tasks* for the next fifteen minutes with no interruption by the author. After approximately fifteen minutes, participants were asked to fill in the section 2 of the questionnaire, which contained 5 items *of environmental satisfaction* in the workspace (5-point Likert scale) and the affect grid. This was the end of section 2 of the questionnaire. Participants were then asked to move back to the waiting area and report their perceived *eyestrain* during the first session by marking a 4-item questionnaire, which was the end of the first session. Approximately 3-minute break was given to the participants while the author modified light condition 1 to light condition 2. The participants were asked to stay in the waiting area during the 3-minute break.

After the break, exactly the same procedure was repeated for the rest of the light conditions except that a relatively long break (10 minutes) was given after conducting 10 sessions of the field study. After the end of fifteen sessions, the field study on that day formally ended and the author cleaned the experimental room by removing all the interiors and lighting fixtures unless there was another participant booked for the experiment. Due to the excessively long duration of the experiment, the study only allowed a maximum of two teams of participants per day (only on weekends)

Table 3.1. List of activities undertaken during the experiment in chronological order

Duration (min)	Light condition	Activities	Area
-1:00~0:00	Default	Preparation of the experiment	
0:00	Dim	Arrival of a participant	Waiting area
0:00~0:09	Default	Introduction	Experimental area
0:09~0:10	Dim	Adaptation	Waiting area
		Start of 1st session	
0:10~0:13	Condition 1	Questionnaire (section 1)	Experimental area
0:13~0:26	Condition 1	Visual task	Experimental area
0:26~0:27	Condition 1	Questionnaire (section 2)	Experimental area
0:27~0:27	Dim	Questionnaire (section 3)	Waiting area
		End of 1st session	
0:27~0:30	Dim	Break	Waiting area
		Start of 2st session	
0:30~0:33	Condition 2	Questionnaire (section 1)	Experimental area
0:33~0:46	Condition 2	Visual task	Experimental area
0:46~0:47	Condition 2	Questionnaire (section 2)	Experimental area
0:47~0:47	Dim	Questionnaire (section 3)	Waiting area
		End of 2nd session	
0:47~0:50	Dim	Break	Waiting area
0:50~1:10		Condition 3 + break	
1:10~1:30		Condition 4 + break	
1:30~1:50		Condition 5 + break	
1:50~2:10		Condition 6 + break	
2:10~2:30		Condition 7 + break	
2:30~2:50		Condition 8 + break	
2:50~3:10		Condition 9 + break	
3:10~3:30		Condition 10 + break	
3:30~3:40	Dim	Break	Waiting area
3:40~4:00		Condition 11 + break	
4:00~4:20		Condition 12 + break	
4:20~4:40		Condition 13 + break	
4:40~5:00		Condition 14 + break	
5:00~5:20		Condition 15	
5:20		**End of 15th session**	

3.2.6 Pilot experiment

Before the main field experiment was conducted, a pilot experiment took place from 4th June 2016 to 12th June 2016 with seven participants (four male and three females who were in their twenties). The purpose of the pilot experiment was (1) to test whether the proposed experimental procedure was both physically and psychologically sustainable and (2) to find out whether the developed questionnaires effectively conveyed the variables to the participants. In fact, the final procedure in the previous section was modified by the findings from the pilot experiment. This section, therefore, explains the findings of the pilot experiment in more detail.

In the earlier pilot experiments (4th and 5th June 2016), each light setting took approximately a half an hour, which was almost 10 minutes longer compared to the final procedure. Such duration of a session was mainly due to the presence of a defined visual cognitive task. The visual task was reading one of fifteen short newspaper articles, roughly 300 words length (10 minutes), and summarising (5 minutes) the contents of what they had just read to author who was sitting next to them. As explained earlier in this chapter, many investigators such as Newsham *et al.,* (2004) and Wang and Boubekri (2010) have used such a method to include complex cognitive performance as a variable in their studies.

Consequently, the experiments started from 10:00 a.m. and ended almost at 5:00 p.m. All of the three participants who were involved in these earlier pilot experiments, reported extreme physical and psychological tiredness and informed the author that such tiredness influenced negatively their perceived experiences under the experiment. Therefore, there was a need to reduce the total duration of the experimental time. Apart from the duration of the experiment, they also pointed out two particular causes that resulted in extreme tiredness. First, reading and summarising the newspaper articles for fifteen times in a row was a not a motivating task especially since they knew that there was no measurement of their performance. Second, it was suggested by two participants that if they were allowed to bring their friends or classmates to participate together, it would enhance their mental motivation.

Based on these suggestions from the earlier part of the pilot experiment, the experimental procedure was modified as follows. Each session of the experiment was reduced from 30 minutes to 20 minutes as explained in Table 3.1. The defined visual task was removed from the experiment and instead the author asked the participants to bring their own tasks. As a result, all the participants in this phase brought their own laptop and performed their real visual tasks such as developing a 3D model by a computer programme and writing up their thesis.

Another implication from the earlier pilot experiment was that a clear explanation of terminology, especially in the affect survey, in the questionnaire must be provided prior to the start of the experiment. For example, four participants who were non-native English speakers in the pilot experiment reported to the author that they had intentionally not marked the adjectives such as ‘sluggish’, ‘jittery’ and ‘placid’ as they were not familiar with the terms. Therefore, in the main experiment, an introductory session was added prior to the beginning of the first setting until all of the participants were fully familiar with the terms used in the questionnaire.

Overall, based on the above implications from the pilot experiment, the main experimental design was updated with regard to its experimental procedure (being shorter), variable definitions (changes in visual tasks) and the addition of the introductory session.

In summary, this chapter first explains how the lighting designers were selected and what their tasks were in the first phase of the study. Also, explanations of the kit of parts (lighting equipment) and target space were given. Then, the chapter explains how the controlled experiment was designed. The techniques such as how to randomise the order of the settings and how to control the light settings were explained. The chapter, then, describes the dependent variables, which were ‘appearance’, ‘emotion’, ‘environmental satisfaction’ and ‘eyestrain’. Lastly, explanations of experimental procedure, and the characteristics of the participants were given.

Chapter 4

Lighting designers' perspective of emotion-based lighting design

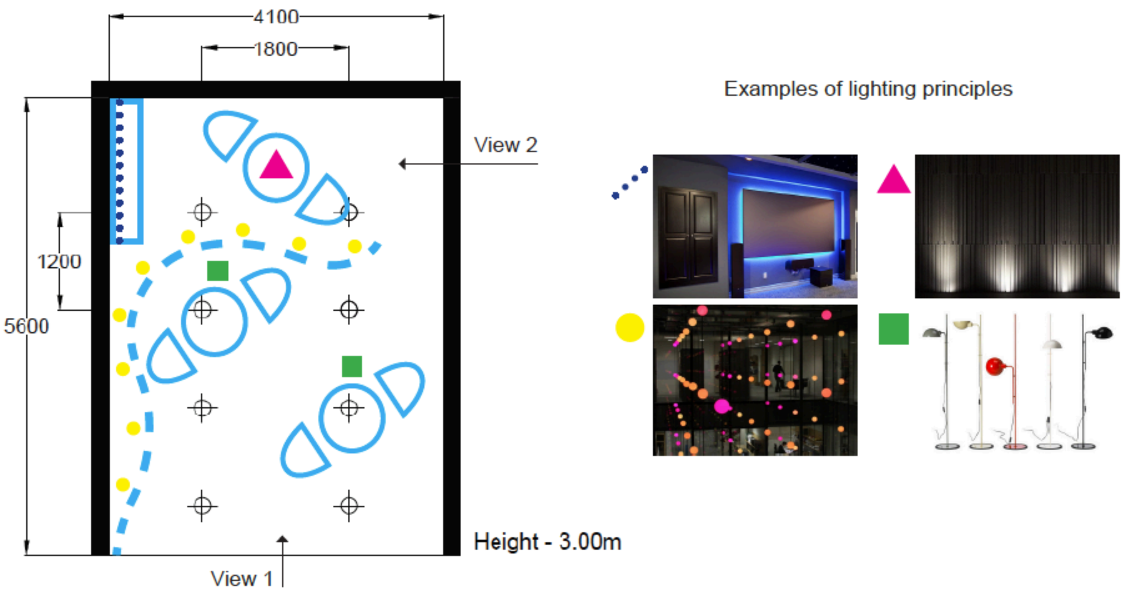
This chapter first describes the ten design concepts produced by the five participating lighting designers. The aim of this process is to conceptualise design elements or design approaches, which could promote 'lively' or 'relaxing' human affect to workspace users. Once the group of design pattern was analysed, this chapter then explains the process of converting the concepts into light settings for the experiment.

4.1 'Lively' concepts

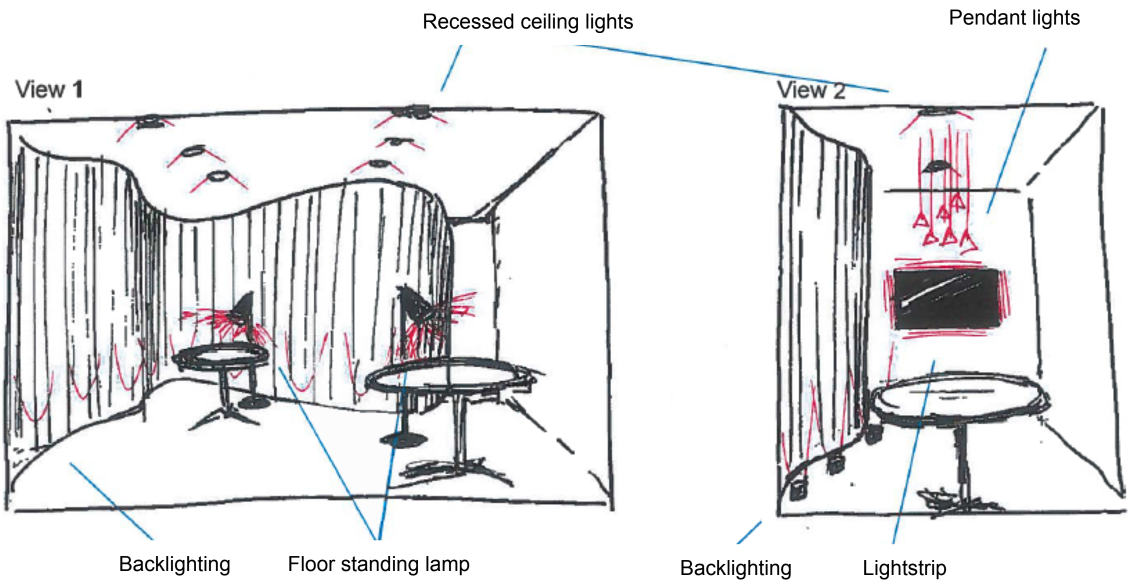
Five suggested lively concepts from the designers are represented as lively concept 1 to lively concept 5 in this study. Some lighting designers suggested their light fixtures with a separate layout plan as well as a hand-drawn sketch and some presented their suggested light fixtures and layout using a computer-generated image. As explained in Chapter 3, although the designers were encouraged to explore their design ideas in a relatively non-strict way by allowing them not to slavishly follow the current codes or lighting recommendations, there are four points that this study expects to see from their design concepts. First, there should be an attempt to accommodate an <u>aesthetic quality</u> in their designs. Second, a lit environment in their designs should ensure <u>acceptable level of visual performance</u> and task productivity. Third, using a <u>colour tuneable technology</u> in their luminous environment is recommended. Lastly, the designs should ensure acceptable level of <u>visual comfort</u> as the main purpose of the space is an office environment Therefore, all the 'lively' concepts in this section are explained in relation with the above four points. This section first introduces the cropped images of their design concepts and their design considerations as well as the installation specifications. The original five design concepts are also attached as Appendix 4 to Appendix 8.

4.1.1 Lively concept 1

Designer 1 has suggested his concept of a lively workspace by a hand-drawn sketch and a lighting fixture layout as shown in Figure 4.1. How has the designer approached to create an aesthetic quality in his design? The answer is that the designer has created a curved room partition to divide the workspace into two different areas for different purposes. According to his explanation, such a curved partition was intended to enhance the architectural context in the space. Further, he has suggested putting several GU10 lamps in the back of the partition so that it becomes a self-luminous light source with a direction pattern, which the intention is to create visual interest in the field of view while not provoking visual discomfort. In order to provide an adequate light level for most of visual-related task performance he has used multiple light sources for the task area. As shown in Figure 4.1, pendant lights and floor lamps as well as recessed ceiling lights are used as the main source of lighting to cover most of the task areas. The designer also explained that he intended for workspace users to freely move around the task area. He also gave specific ideas of intensity and colour properties of each of the light sources.



(a) The layout of the lighting fixture



(b) The hand-drawn sketches

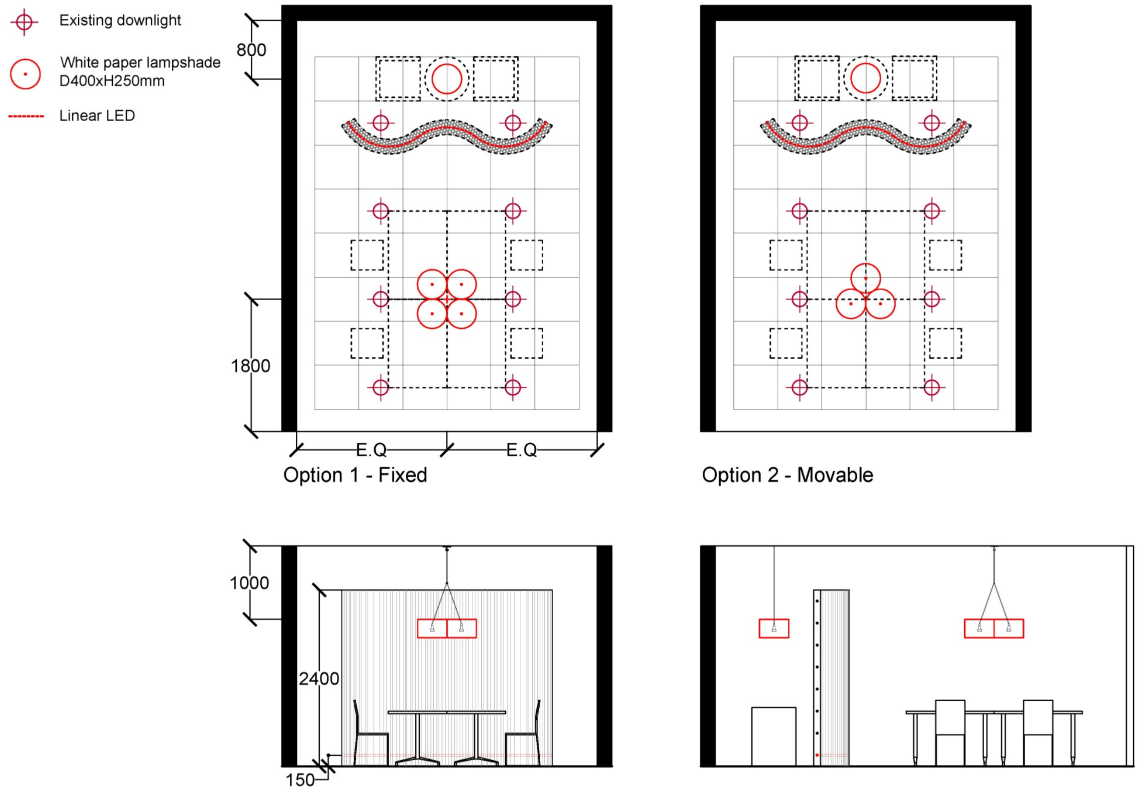
Figure 4.1. Lighting design concept 1 for a lively workspace

First, in his design concept, the ceiling lights were set to a CCT of 4000K with 70% output in intensity. He suggested using 6 of A19 lamps to configure the pendant lightings. He has also included colour-changing effects from the pendant sources. Half of the pendants are suggested to be in a colour loop of saturated red, blue and green (time sequencing: 2 minutes) with only 25% output in intensity, whereas the other half are suggested to be set at a CCT of 4,000K and 70% intensity. The floor lamps were also suggested to be fitted with A19 lamps and to be set at the CCT of 4,000K. Lastly, the backlighting and the lightstrips are to be set at the same colour loop as the pendant lights.

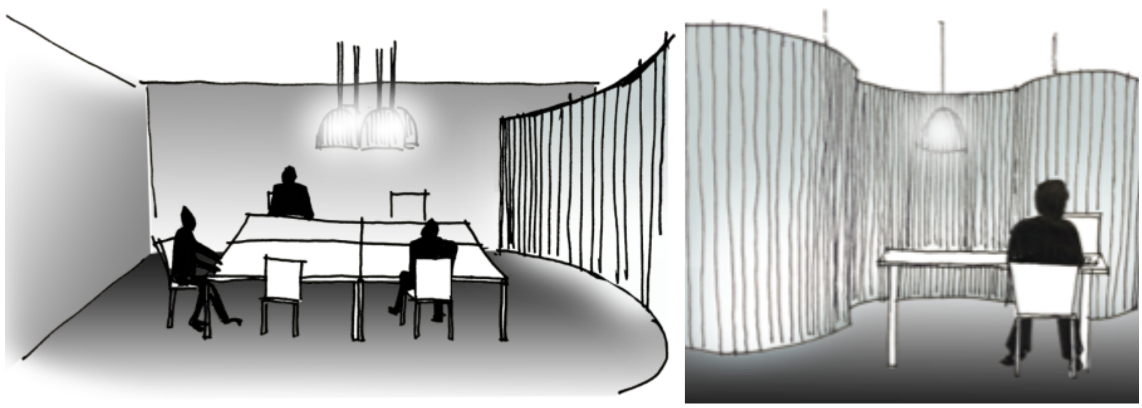
4.1.2 Lively concept 2

Designer 2 has also suggested her concepts of a lively workspace with a layout of the lighting fixtures and hand-drawn sketches as shown in Figure 4.2. She has also created a curved partition to divide the space into two different areas, which are to for group and individual uses. She described that the main aim of her lighting design is to make workspace users feel good both physically and mentally as well as promoting their concentration and motivations for related tasks. She has also suggested to put lightstrips within the curved partition that to become a self-luminous light source but unlike lively concept 1, she intended to have uniform light effects on the partition.

She described the self-luminous partition as a ‘breathing wall’ that creates decorative textile pattern by subtle use of dynamic lighting in white tones, ranging from 3,000K to 5,000K over time. She has intended that workspace users feel relaxed by looking at the self-luminous partition, especially in a windowless environment. In summary, the designer has created a slowly colour-changing self-luminous partition in the room that could enhance both an architectural and aesthetical context.



(a) The layout of the lighting fixture



(b) The hand-drawn sketches

Figure 4.2. Lighting design concept 2 for a lively workspace

As shown in Figure 4.2(b), pendant lights (A19 lamps) with a sphere-shaped lampshade are also suggested for main task lighting, which are to create diffuse light effects on the task area. The designer mentioned that having a diffused overhead lighting could provide required level of visual comfort. In order to provide an adequate level of light for visual performance, she has included two main light sources in the task area. She suggested using the ceiling lights only to supplement the other lighting in order to meet the required illuminance levels on the horizontal task plane. For the lively concept, her target illuminance was between 600 lx to 800 lx.

4.1.3 Lively concept 3

Designer 3 suggested a concept of a lively workspace with a section and a floor plan of lighting fixture layouts, as shown in Figure 4.3. Unlike the earlier two cases, although she has created two different types of task areas, individual use and meeting use, there was no use of the partition. Then, how has the designer approached to accommodate an aesthetic quality in her lively workspace design? She explained that having a wall-washing light pattern could lead an increase of visual interest in the room.

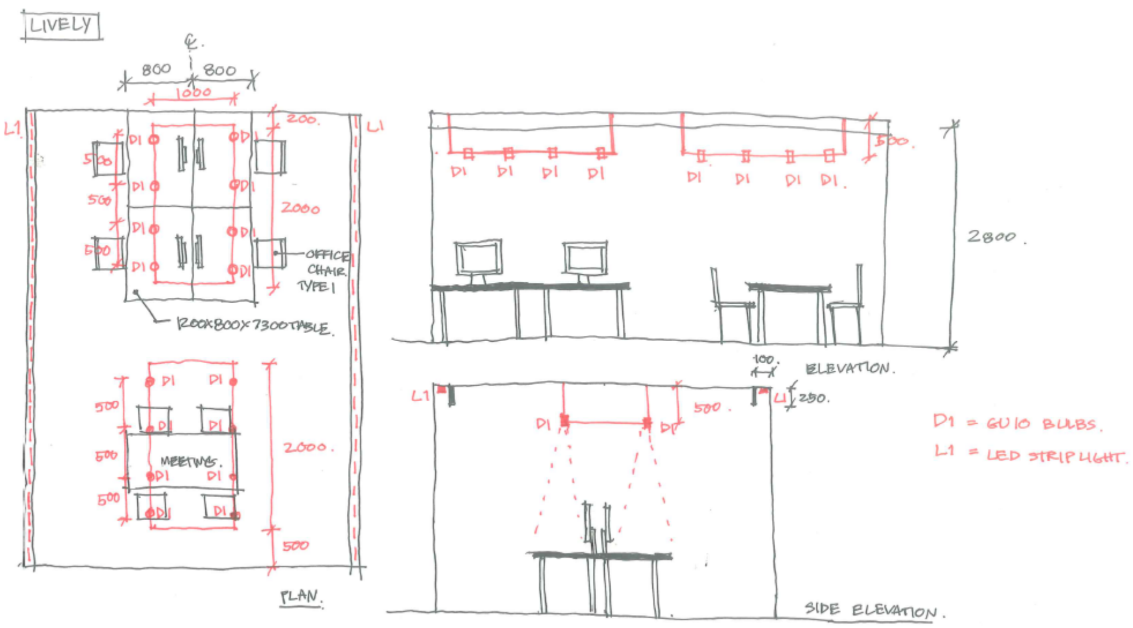


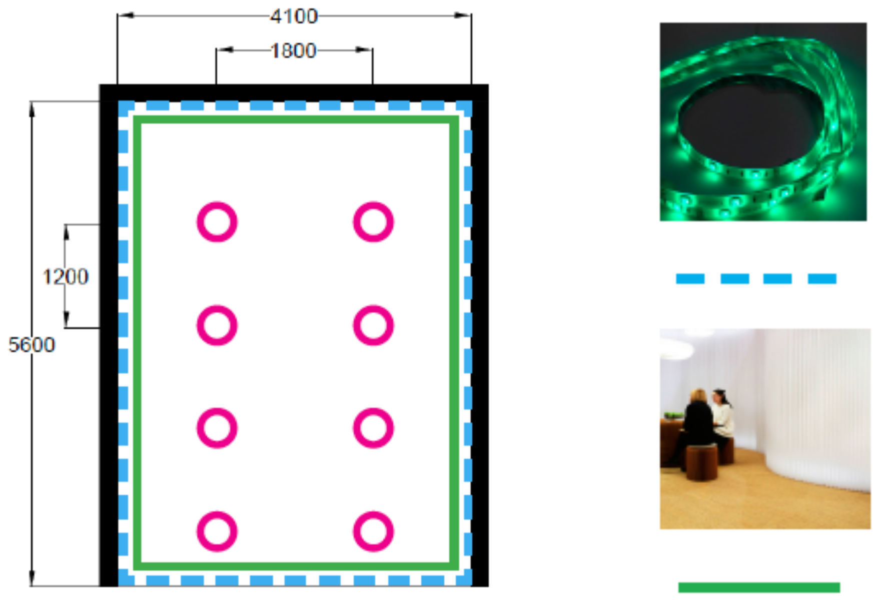
Figure 4.3. Lighting design concept 3 for a lively workspace

In her design concept, there is no use of the ceiling lights and instead sets of suspended pendent lights with GU10 lamps were suggested as the main source of light. She commented that lighting from such directional, narrow-beam lamps were to shine down on the task area between a computer screen and a worker and this would be adequate for most of visual task performance.

She also explained the reason of having closely neighbouring task areas, as to make users feel livelier by seeing each other's activities (e.g. work-related tasks). All of the lights used in her design concept was set to a CCT of 4,000K with no changes as the designer believed that applying a colour-tuneable technology in a workspace environment could cause unwanted visual discomfort.

4.1.4 Lively concept 4

Designer 4 suggested his concept of a lively workspace by using only the ceiling lights, and the self-luminous partition. In his design, lightstrips are concealed at the perimeter of the ceiling to backlight the translucent partition, which covers all of the wall surfaces as shown in Figure 4.4(a). Then, the lightstrips were set to be in a colour loop from cool white (5,000K) to saturated blue (see Figure 4-4(b). The designer suggested that the surrounding self-luminous partition, which continuously changes its colour properties could play a key role in increasing the aesthetic quality of the room. In order to ensure an adequate light level for a visual task, the downlighting from the ceiling lights that are set to a CCT of 5,000K provides functional lighting to the workspace users.



(a) The layout of the lighting fixture

(b) The image of expected concept

Figure 4.4. Lighting design concept 4 for a lively workspace

4.1.5 Lively concept 5

Designer 5 suggested his concept of a lively workspace as shown in Figure 4.5. The design concept uses the ceiling lights, pendant lights and narrow-beam GU10 lamps as the main source of lighting. Further, the curved partition is included not for the dividing the use of space but to enhance the context of the architectural interior according to his explanation. He commented that it was the intention of the lighting design to create a setting for stimulation. He went on to state that the aim was to create a sense of time passing and an artificial connection with the outside.

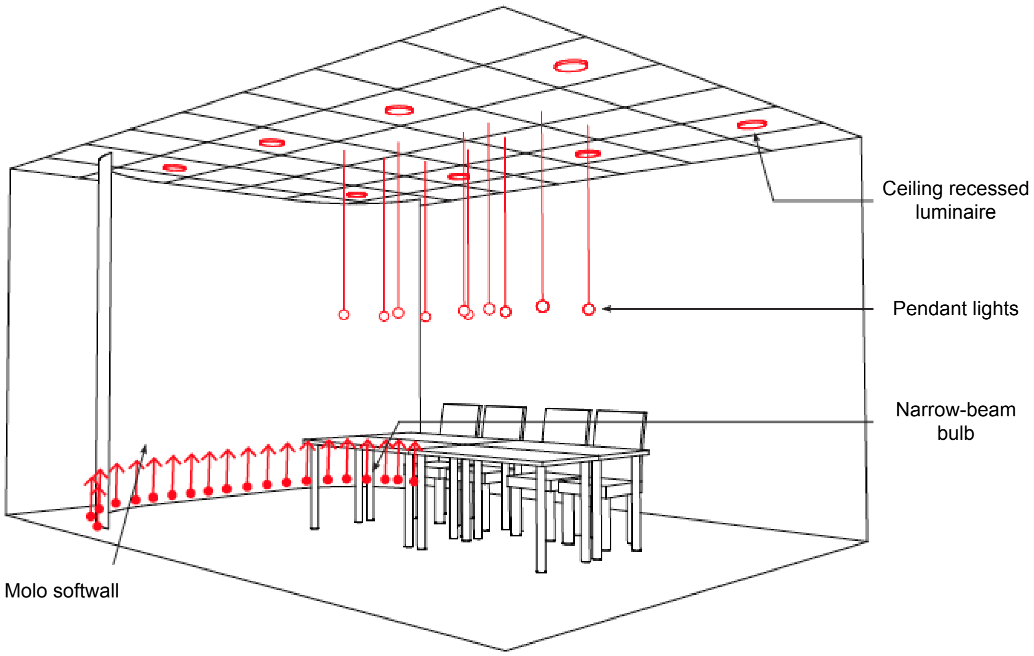


Figure 4.5. Lighting design concept 5 for a lively workspace

In order to achieve such an aim an array of narrow-beam (GU10) lamps are mounted behind the curved shaped partition to graze the surface. It was suggested that the lamps slowly and individually vary their intensity and colour from saturated blue to cyan, and from 25% to 100% intensity. He claimed that such a created screen would act as a main feature in the space and a point of focus.

Another feature in his design concept was the use of pendant lights (A19 lamps). The suspended pendant lights were also suggested to slowly vary in intensity and colour, from 4,000K to 6,500K and from 50% to 75% of output. He described that such a sequencing would give the impression of clouds passing overhead to the workspace users. Lastly, downlighting (50% of output) from the ceiling lights are used without a change in intensity but slowly changing CCT from 4,000K to 6,500K. This sub-section has so far introduced the suggested design concepts of ‘lively’ workspaces by 5 different lighting designers. Before comparing their design patterns and elements, the other 5 lighting designs of ‘relaxing’ workspaces by the same designers are explained in the next sub-section.

4.2 ‘Relaxing’ concepts

Again, five suggested relaxing concepts from the designers are represented as relaxing concept 1 to relaxing concept 5 in this study. Some of the lighting designs are not different from the lively cases with regard to the physical layout of furniture and lighting fixtures but noticeable changes in luminous condition are found. Their concepts are introduced in the same way as the lively cases. The original five design concepts are also attached as Appendix 4 to Appendix 8.

4.2.1 Relaxing concept 1

Designer 1 suggested the same physical layout of the interior furniture and light fixtures could be applied to his idea of a relaxing workspace. In other words, he believes that changes in luminous conditions are strong enough to make feelings from workspace users change from ‘lively’ to ‘relaxing’. As shown in Figure 4.6, the only difference regarding lighting fixture layout compared to lively concept 1 is the direction of the floor lamp. The floor lamps are directed to the ceiling unlike the case of lively concept 1, which is directed to the task area.

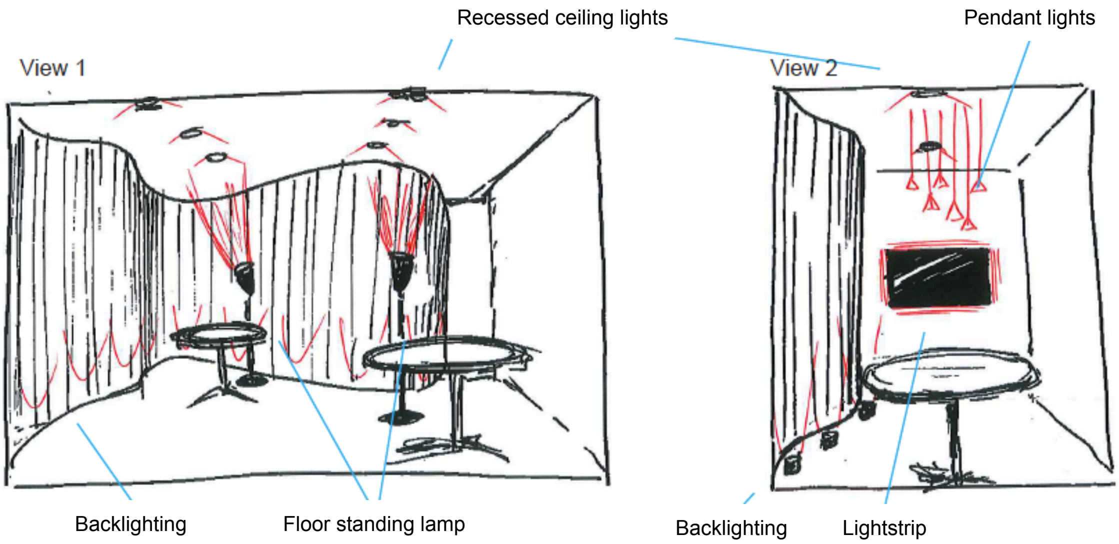


Figure 4.6. Lighting design concept 1 for a relaxing workspace

The designer again used the curved room partition to enhance an architectural and aesthetical quality of the workspace. By putting an array of narrow beam lamps (GU10 bulbs) behind the curved partition, he transforms the partition into a self-luminous block with a directional light pattern. In terms of suggested use of colour and intensity of light sources, it differs completely from the previous case. First, the ceiling lights are set to be a CCT of 3,000K and dimmed by 30% of its intensity. Instead of using a colour loop in saturated colours of RGB, he suggested using a slow (5 minutes) pastel tone colour sequence. The other halves of the pendant lights are set to be at 3,000K instead of 4,000K. The floor lamps are also designed to be in a colour loop of RGB pastel tones with 5 minutes per loop. Lastly, the self-luminous partition is designed to change its colour slowly (30 minutes) from 3,000K to 6,000K.

4.2.2 Relaxing concept 2

Designer 2 also expressed her view that changing intensity and colours from the light sources could successfully influence workspace users’ emotional state from ‘lively’ to ‘relaxing’ once the visually appealing design of the physical layout is set. Similar to her another design concept of a lively workspace (Lively concept 2), the curved room partition is used as a self-luminous source that enhances an architectural context in the room and the sphere-shaped lampshades are used to create diffused lighting distribution from an overhead direction. The designer commented that such lighting distribution is particularly intended to create a feeling of visual comfort to its users.

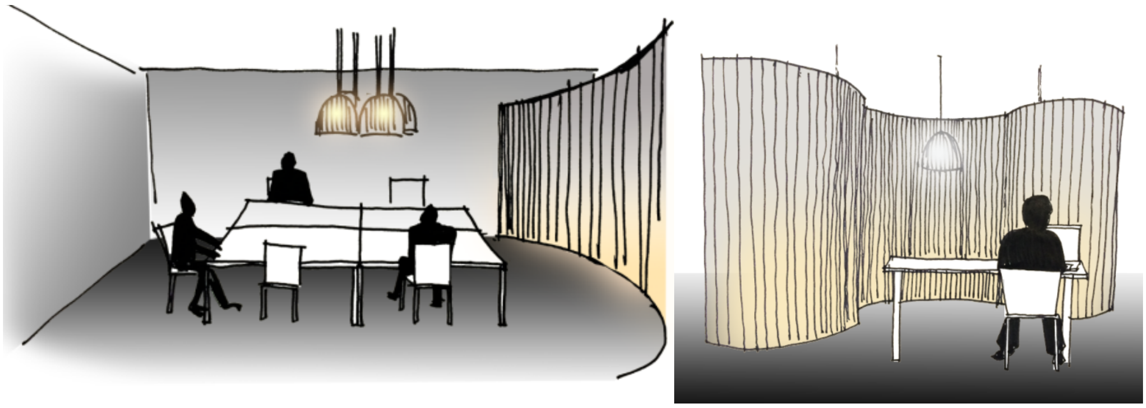


Figure 4.7. Lighting design concept 2 for a relaxing workspace

As shown in Figure 4.7, her design approach for a relaxing workspace is mainly to use warm white light sources with a lower light level. She explained in her design concept that a lower lighting level and warm white 3,000K light sources would make people's skin tone look healthy as long as the ambient light is bright enough to see each other's facial interaction (The designer might have a metric such as E_{cyl} (mean cylindrical illuminance) in mind). She suggested the minimum level of illuminance on the horizontal working plane to be between 300 lx to 500 lx.

4.2.3 Relaxing concept 3

Designer 3 again suggested her concept of a relaxing workspace with a section and a floor plan of lighting fixture layouts, as shown in Figure 4.8. Unlike the earlier two cases (relaxing concept 1 and relaxing concept 2), she expressed her view that there is a more suitable physical layout of interiors and lighting fixtures to make people feel more relaxed. She suggested that having private seating and a working space for each worker is important for them to feel relaxed and therefore the physical layout of interior furniture is designed in a such way that an individual cannot look at each other's task activities. In terms of lighting design, she suggested using two table lamps only (equipped with A19 lamps) for the main source of lighting. She highlighted the importance of avoiding any direct light at individual eye level in the concept. Apart from the task area, she intended to create a cove effect on the sidewalls as well as having three suspended pendant luminaires for meeting purposes. According to the designer's explanation, the cove effect on both sidewalls is intended to accommodate required aesthetic quality from the design brief stage. In her concept of relaxing workspace, all light sources are to be concealed either inside a lampshade or by interior details. Lastly, she proposed to set all light sources at a fixed CCT of 2,700K.

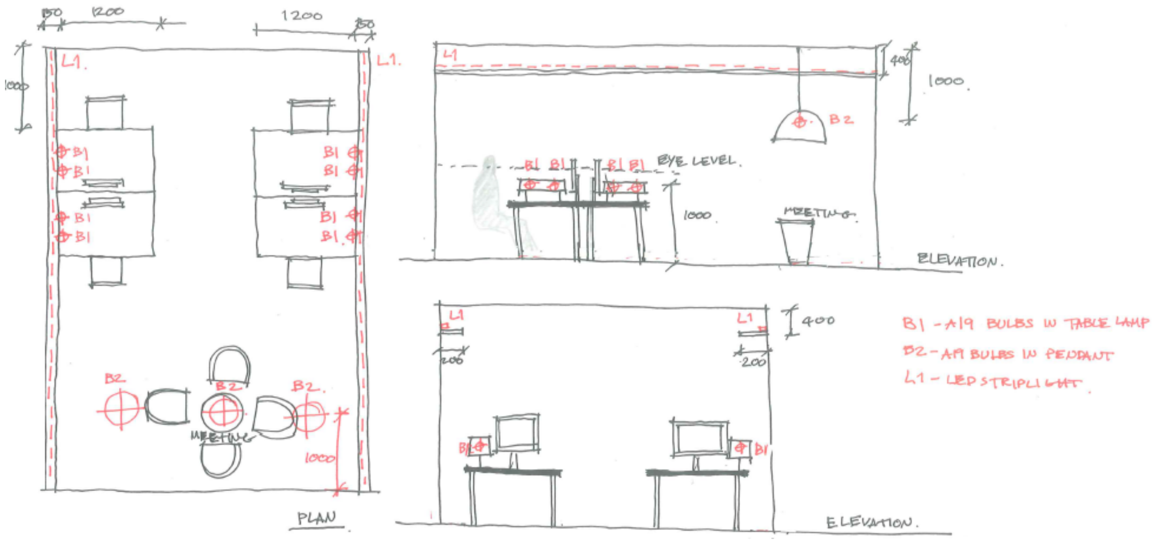
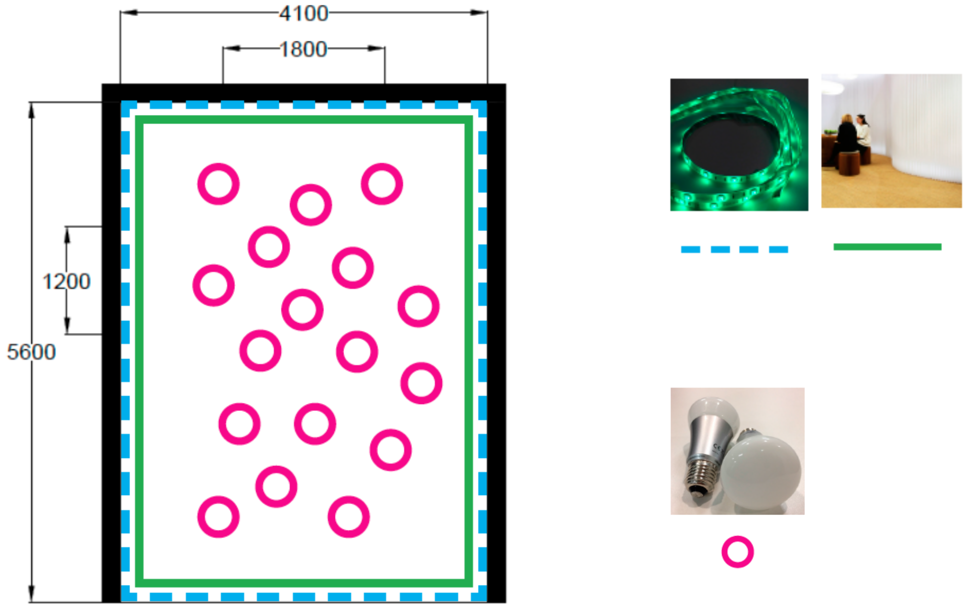


Figure 4.8. Lighting design concept 3 for a relaxing workspace

In summary, the designer used different light patterns to create different ambiences of the space. A lighting pattern of wall-washing is used to create lively ambience whereas a pattern of cove effects is used to create relaxing ambience. In her design concepts, using a colour-tuneable technology is not applied.

4.2.4 Relaxing concept 4

Designer 4 has modified the layout of lighting fixtures compared to his concept of a lively working space by adding an element of suspended pendant lights on the task area, as shown in Figure 4.9. In his concept of a relaxing workspace, yellow lighting is used in the near floor area as shown in Figure 4.9(b). He suggested to put light strips in the down side of the self-luminous partition to create such atmosphere. Further, the lightstrips are to be set in a colour loop from yellow to white light of 4,000K. For the suggested pendant lights (equipped with A19 lamps), all lamps are to be set at 2,700K to illuminate the task area and they are the only main light sources for task lighting. He suggested not using the ceiling lights to create a relaxing mood for the workspace users.



(a) The layout of the lighting fixture

(b) The image of expected design

Figure 4.9. Lighting design concept 4 for a relaxing workspace

4.2.5 Relaxing concept 5

The concept of relaxing workspace suggested by lighting designer 5 is shown in Figure 4.10. He described his inspiration of the scheme as 'work by candlelight' and 'burning the midnight oil'. He explained his approach to achieve such aims by using mainly warm white lights (2,000K and 2,700K) to mimic incandescence. He described the best purpose of this workspace was for private and quiet study. In his lighting design, there was no form of downlighting, and therefore the ceiling lights are not used. Similar to the relaxing concept 3, the main sources of lighting are only table lamps, equipped with A19 lamps (2,700K). Noticeably, there are floor corner uplighters (GU10 lamps) in the design concept. He explained the purpose of such lights as providing narrow-beam accent light for indirect atmospheric effects. For achieving such effects, the GU10 lamps are set at 2,000K.

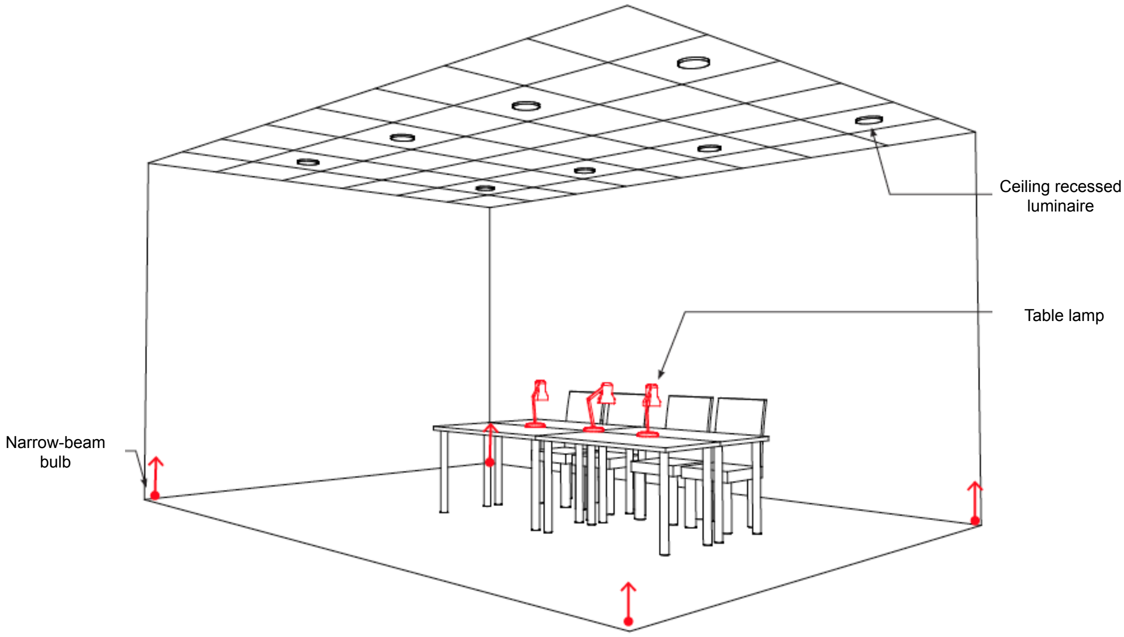


Figure 4.10. Lighting design concept 5 for a relaxing workspace

This study has illustrated all of the lighting concepts by the designers and has explained their design aims, intentions and related specification of both lighting elements and design elements. How have the lighting designers approached the configuration of workspaces that are either 'lively' or 'relaxing'? Are there any common design patterns or elements in their approach?

4.3 Design analysis of the concepts

The detailed description of the specific intensity and colour characteristics of each lighting design is excluded in this section as the analysis of them by their photometric and colorimetric characteristics is conducted and explained in Chapter 5. This study reports a variety of design responses from the lighting designers although working with a kit of parts might have been a challenging task. This study has divided the lighting designs into two different aspects, distribution of light, and use of dynamic lighting (dynamic lighting is defined here as a lighting that changes both colour and intensity over a time).

The reason for considering the distribution of light as an important element here is based on the findings from the past literature. Several studies such as ‘Flynn *et al.* (1979) and Loe *et al.* (1994) suggested that lighting distribution in the field of view influences human subjective impression of a space. The use of dynamic lighting was chosen as to see whether the smart technology can be embedded in the lighting design, which was also stated in the design brief document. A total of ten questions were developed based on such aspects. Physical layout of the suggested interior is also considered as a separate question. Therefore, group analyses on the five ‘lively’ and the five ‘relaxing’ design concepts are separately conducted based on the eleven questions as shown in Table 4.1.

Some patterns were also noticed between within-designer transition from ‘lively’ to ‘relaxing’. For example, Designer 1 and Designer 2 did not suggest a change of furniture layout between a transition from ‘lively’ to ‘relaxing’. Instead, they suggested to use different colour properties of the light sources. Designer 1 suggested a change of CCT from 4000K to 3000K (ceiling lights) and a change from RGB saturated colours to RGB pastel tone colours (self-luminous partition, pendant lights) to cause ‘lively’ to ‘relaxing’ atmosphere. Similarly, Designer 2 suggested a change of CCT from 4000K to 3000K (pendant lights) and a change from a colour changing of 3000K-5000K to a fixed CCT of 3000K to transit users’ feelings from ‘lively’ to ‘relaxing’.

Designer 3 and 5 also changed their approach of colour properties to create a different ambience. Although their approaches for a ‘lively’ workspace were completely different, both suggested to use a fixed CCT of 2700K of table lamps for their ‘relaxing’ concepts. It clearly suggests that although there is no eminent pattern noticed in relation with their lively concepts, the designers somehow prefer to use light sources with CCT either 27000K or 3000K when creating an ambience of ‘relaxing’.

Table 4.1. Eleven criteria for grouping design elements of the ten concepts

Design aspects	Considered criteria for the analysis
Lighting design by distribution of light	1. What were the main sources of lighting for the task area? 2. Did it come from overhead direction? 3. Did it include a use of lampshade? 4. Was there accent lighting used for creating some pattern in the field of view? 5. Which direct did it come from? 6. What lighting patterns were created by such lighting? 7. Did the concept create a self-luminous partition?
Lighting design by use of dynamic lighting	8. Did the concept include continuously changing of CCTs? 9. Did the concept include a coloured lights that continuously changing? 10. Did the concept include a continuous change in intensity of light sources?
Non-lighting design aspects	11. Any of special notes made by the designers?

4.3.1 Analysis of 'lively' concepts

First, lighting distribution under the five lively concepts were analysed. Table 4.2 shows a comparison of five lively concepts by distribution of light, which responds to seven questions (Q1 to Q7) in Table 4.1. It is immediately noticed that all the five lively concepts used more than one overhead down-lighting for the main lighting. According to Flynn *et al.* (1973), using overhead lighting only (either low intensity or high intensity) could result in a poorer 'evaluative' impression of a space such as monotonous, dislike, and unpleasant than using both overhead and wall lighting (See Figure 2.4). Perhaps, the designers knew such potential danger by their instincts and have included accent lighting in their concepts (five out of the five). Four out of the five concepts included a use of pendant lighting. This is perhaps a way of creating visual interest in their minds. In terms of the intended lighting pattern from the accent lighting, it is noticed that four out of the five concepts included a directional effect caused by either uplighter or down-lighting. Only one (Lively 2) concept intended to create a rather diffused and uniform lighting distribution by including a sphere lampshade and a uniformly lit self-luminous partition.

Table 4.2. A comparison of light concepts by distribution of light (lively concepts)

	Lively 1	Lively 2	Lively 3	Lively 4	Lively 5
Main sources of light	RC, PL, FL	RC, PL	PL	RC	RC, PL
Overhead direction?	Yes	Yes	Yes	Yes	Yes
Lampshade?	No	Yes	No	No	No
Accent lighting?	Yes	Yes	Yes	Yes	Yes
Direction of the accent lighting?	Curved partition	Curved partition	Side walls	Curved partition	Curved partition
Intended lighting pattern?	Directional (uplight)	Uniformly lit	Wall-washing	Directional (downlight)	Directional (uplight)
Self-luminous partition?	Yes	Yes	No	Yes	Yes

Note: RC=recessed ceiling lights, PL=pendant lights, FL=Floor lamps, TL=table lamps.

Lastly, the curved self-luminous partition was mostly applied in the lively concepts (four out of the five). Several designers commented that an inclusion of the curved self-luminous partition was to increase an architectural context of their design concepts. The author also suspects that since the target space was given as a form of a windowless room, the designers created the self-luminous partition that users of the space can a perception of being artificially connected to an outside view.

Table 4.3. A comparison of light concepts by use of dynamic lighting (lively concepts)

	Lively 1	Lively 2	Lively 3	Lively 4	Lively 5
Varying CCT?	No	Yes	No	No	Yes
Varying colours?	Yes	No	No	Yes	Yes
Varying intensity?	No	No	No	Yes	Yes

In terms of the use of dynamic lighting, four out of the five lively concepts included at least either of varying CCT or varying colours in their designs as shown in Table 4.3. Another noticeable feature is the use of saturated colours, which three out of the five have adopted in their approaches. Saturated colours are only applied to create either directional or cove effects within the self-luminous partition (non-task area) and all of them were suggested to be by dynamic lighting. The designs that comprised of more than two different CCTs were also observed (two out of the five).

Overall, it was observed that the lighting designers have, in general, intended to create lively workspace scenes that contain contrast and dynamics of both saturated and white colour in either a directional pattern or a cove effect by adding self-luminous interior design elements. Most of their intended contrast or dynamics are distant from the main task area but not from the overhead direction. For the main source of lighting, all of them have opted to use direct lights from an overhead direction, but it is also noticed that adding suspended pendant lights as well as conventional ceiling lights seem to be preferred.

4.3.2 Analysis of 'relaxing' concepts

The characteristics of lighting distribution in the relaxing concepts are summarised in Table 4.4. Different trend is easily noticed. First, it was observed that the avoidance of using ceiling lights for the relaxing designs over the lively concepts. Table lamps or pendant lights are the most frequently suggested for the main source of lighting. This is perhaps because that the designers intends to create a feeling of intimacy with the above light sources. Another feature from the relaxing designs was that the designers tended not to use more than one light source for the main illumination whereas two of the five use multiple light sources for main illumination in the lively concepts.

Table 4.4. A comparison of light concepts by distribution of light (relaxing concepts)

	Relaxing 1	Relaxing 2	Relaxing 3	Relaxing 4	Relaxing 5
Main sources of light	RC, PL	PL	PL, TL	PL	TL
Overhead direction?	Yes	Yes	No	Yes	No
Lampshade?	No	Yes	Yes	No	No
Accent lighting?	Yes	Yes	Yes	Yes	Yes
Direction of the accent lighting?	Curved partition	Curved partition	Side walls	Curved partition	At the corner of the wall
Intended lighting pattern?	Directional (uplight)	Uniformly lit	Cove effects	Directional (uplight)	Directional (uplight)
Self-luminous partition?	Yes	Yes	No	Yes	No

In terms of the use of non-main light sources, it seems that there is only minor difference in their approaches from the lively design concepts. Again, all of them have included subsidiary lights to create certain patterns in the field of view as shown in Table 4.6. The directional effect by uplighting from the floor level is most observed. However, there is a difference in frequency in having the self-luminous design elements in the concepts. Two out of the five suggested illuminating the small part of the sidewall surface rather than having a self-luminous interior design element.

It was observed that there was less use of creating contrast and dynamics in different colours in the relaxing concepts and the summary of the five relaxing concepts in these criteria is shown in Table 4.5. Unlike the lively concepts, there was no suggestion of using saturated colours and instead two out of the five designers have added different pastel colours in the field of view. In relaxing concept 5, although there is minor difference in using the different CCTs of lights, of only 700K.

Table 4.5. A comparison of light concepts by use of dynamic lighting (relaxing concepts)

	Relaxing 1	Relaxing 2	Relaxing 3	Relaxing 4	Relaxing 5
Varying CCT?	No	No	No	No	No
Varying colours?	Yes	No	No	Yes	No
Varying intensity?	No	No	No	No	No

4.4 Converting the concepts into settings

4.4.1 Configuration of lighting fixtures

Converting the design concepts into light settings was an essential process to apply the findings of the first phase of the field study into the second phase, an experiment. To configure ten different light settings, ten identical experimental spaces with ten sets of light equipment were ideally required. Due to limited resources (an experimental space, a set of light equipment), simplification of some elements of the concepts were required prior to implementation.

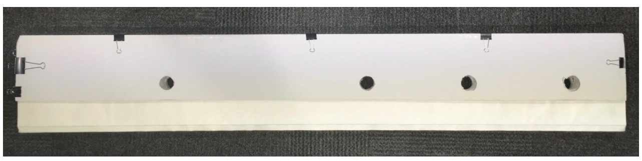
Certain light materials were frequently observed across the concepts and therefore they were first identified as core lighting design elements that must be included in the lighting and furniture layout. Pendant lights were most applied to configure the workspace in seven out of ten concepts (four lively and three relaxing) as well as the use of the self-luminous curved partition (seven times out of ten concepts). The designers also included wall-washing lighting (either downwards or upwards) in six out of ten concepts. Therefore, experimental space was equipped with these three core lighting systems. With regard to the pendant lights, twelve sets of pendant lights were manually constructed by the author, (see Figure 4.11). The following items were used to configure the suspended pendant lights in the experimental space. First, 12 pieces of the black lighting cords (each 8m length), the metal lamp holders and power plugs were used. Second, 12 Philips Hue A19 lamps and GU10 lamps were inserted as a light source. Lastly, 24 ceiling hooks were attached at both a ceiling and a side of wall to suspend the pendant lights. All of the items were bought at nearby Heal's department store, which is known for its high quality contemporary furniture and lighting. Using such high-quality products was intended to create and enhance the architectural context of the experimental space.

(a) Twelve pieces of pendants lights

(b) Suspended pendant lights (equipped with GU10 lamps)

Figure 4.11. Self-constructed pendant light system

After the pendant lights, the translucent curved partition was constructed and located in the experimental room. As shown in Figure 4.12(a), two pieces of white foam board (2,000mm×500mm×10mm) were attached to each side to prevent it from falling down during the experiment. Figure 4.12(b) shows an image of the curved partition mounted with Philips Hue LED strips. Although it looks untidy in the figure, all of the lines and cords were concealed from the field of view during the measurement and actual experiment.



(a) A translucent partition with white form boards

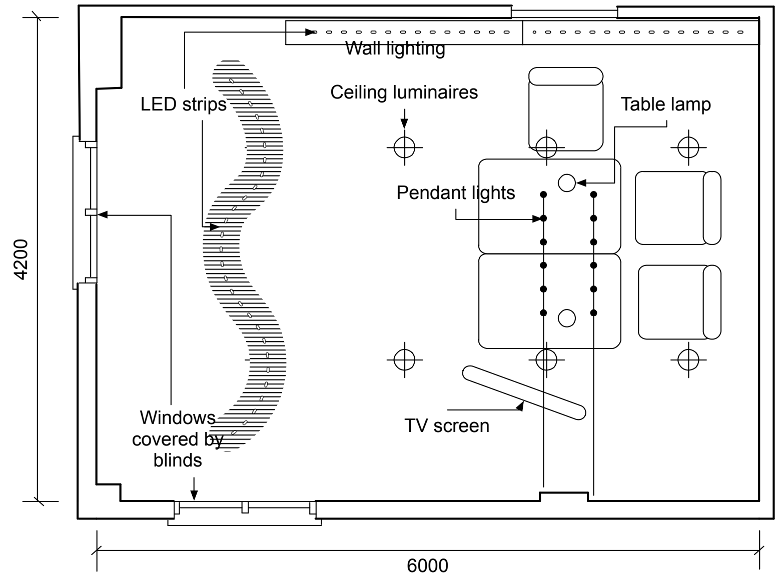
(b) Constructed curved partition with inserted Philips Hue LED strips (in test)

Figure 4.12. A constructed curved translucent partition

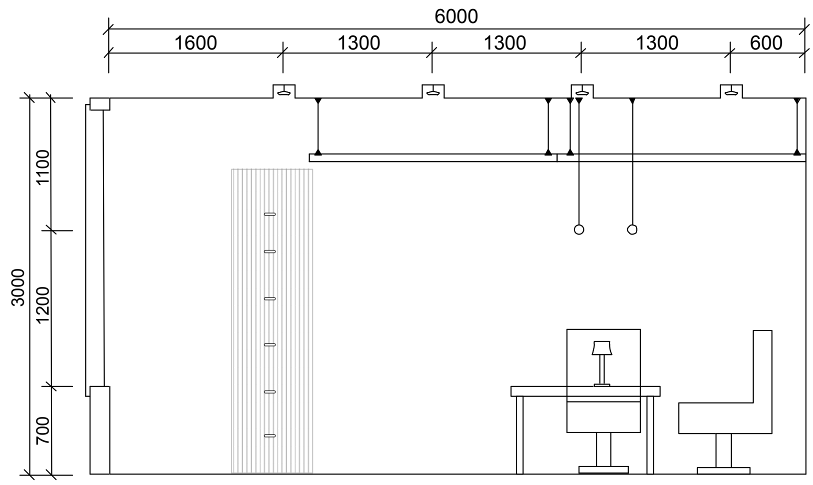
Wall lighting was again self-constructed by the author but due to the limitation of resources, only one wall was used. In total, 8 pieces of white foam board (2,000mm×500mm×10mm) were used to configure a wall shelf with 4 Philip Hue LED strips attached on the shelf surface as shown in Figure 4.13. Transparent fishing line was used to suspend the shelf 400mm below the ceiling.

Figure 4.13. A constructed wall shelf

Aside from the core lighting design elements, two table lamps and a 50'' TV screen with a stand were also added to configure the experimental room (see Figure 4.15). The addition of the TV screen was intended to hide the pendant cords from the field of view but also enhanced the general look of a real-workspace environment. Overall, the lighting fixtures were arranged to give a feeling of a small workspace. Figure 4.14 shows the lighting fixture layout as a floor plan and Figure 4.15 shows a general view of the experimental room setting photographed with a fisheye lens. For convenience, the waiting area of the room is excluded in the drawings.



(a) A floor plan showing lighting fixtures



(b) A section plan showing lighting fixtures

Figure 4.14. A Floor and section drawing for lighting fixture and furniture layout

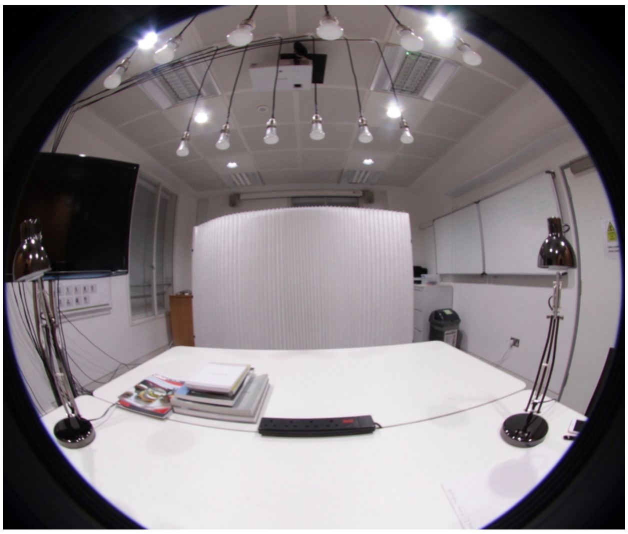


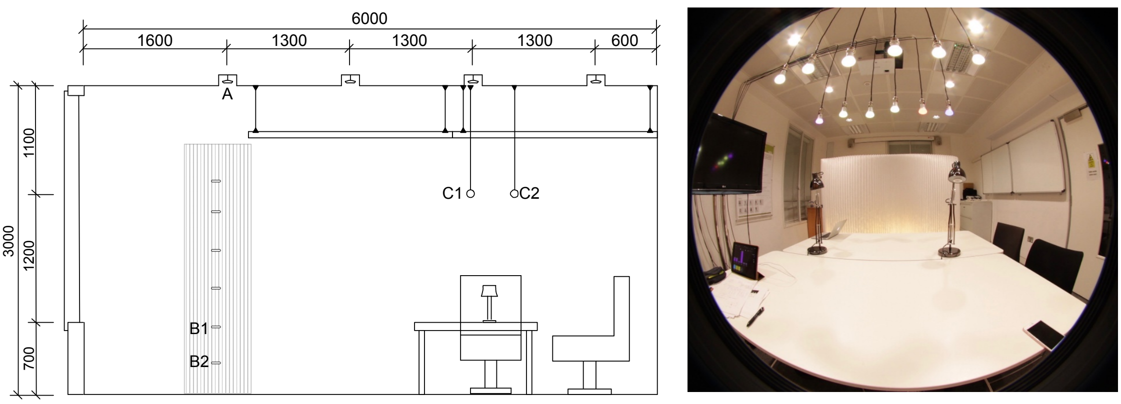
Figure 4.15. General view of the mock-up experimental room photographed with a fisheye lens

4.4.2 'Lively' lighting settings

After the lighting fixture and furniture layout were configured, replication of the ten design concepts into light settings was arranged. The replication was conducted to match the designers' original intention from the concepts to the setting as closely as possible. First, this section explains five lively settings, which are referred to as the lively concepts. In the following descriptions of each setting (both 'lively' and 'relaxing'), CCT values are frequently used to describe the illumination conditions. This is because that the designers provided a specific value of CCTs in their design concepts, and this section intends to show that the replication has been made as much as possible from the original suggestions.

Lively setting 1

Three different light sources were used to replicate the lively concept 1. Figure 4.16(a) shows the light sources used with marks of A, B and C. The ceiling luminaires (A) were set for 70% of intensity at 4,000K as matched by the concept. Originally, the designer suggested to put an array of GU10 lamps behind the translucent partition in order to create a directional light pattern on the partition surface. However, an array of GU10 lamps was not implemented due to limitation of resources during the replication stage. Instead, Philips Hue LED strips (B1 and B2) were mounted inside the translucent curved partition and were set in a color loop of saturated red, blue, and green (sequence time: 2 minutes) to create a similar directional pattern. Six pendant lamps (C2) were set for 70% intensity at 4,000K, while another six pendant lamps (C1) were set for the same color loop of B1 and B2 to match the designer's concept. Figure 4.16(b) shows a fisheye view of the setting.

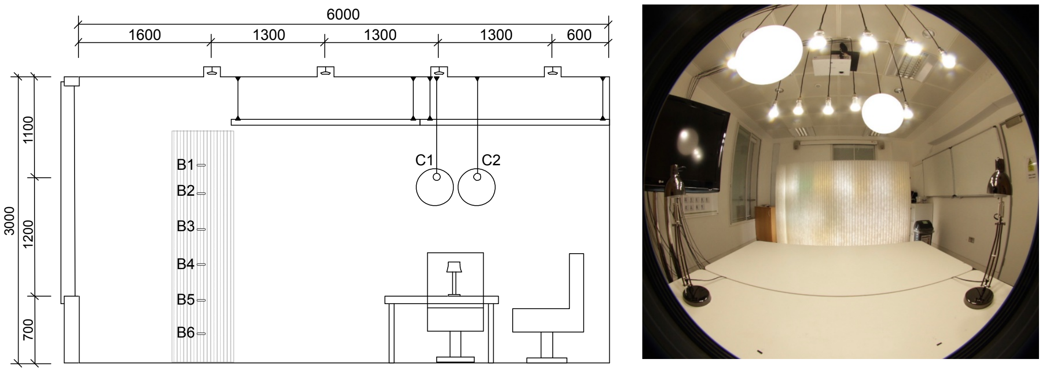


(a) A section drawing for lively setting 1 (b) A fisheye view

Figure 4.16. Lively setting 1 (a section drawing and a photograph)

Lively setting 2

For the lively setting 2, two light sources were used for the replication. Six Philips Hue LED strips (marked as B1 to B6 in Figure 4.17(a)) were mounted inside the translucent partition and were programmed to change their CCT from 3,000K to 5,000K in a slow loop (15 minutes), which matched the designer's instruction. However, with regard to the pendant lights, there was a slight change compare to the concept 2. Although the designer suggested covering all of the pendant lamps by a globe-shaped lamp shade, the author only managed to obtain two shades. Therefore, a mixture of bare lamps and lamp shades was adopted to match the design concept as close as possible, which is shown in Figure 4.17(b). Philips A19 lamps were mounted in the pendant lamp holders and were set for 4,000K.

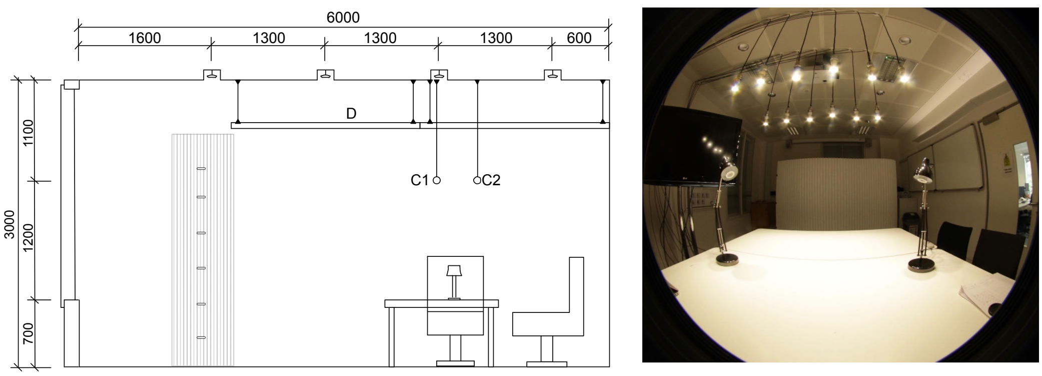


(a) A section drawing for lively setting 2 (b) A fisheye view

Figure 4.17. Lively setting 2 (a section drawing and a photograph)

Lively setting 3

Again, two light sources were used for replication of the lively concept 3, the pendant lamps (C) and wall lighting (D). Twelve of the pendants were equipped with GU10 lamps (C1 and C2) with a setting of 4,000K and Philips LED light strips, which were attached on the wall shelf (D) were also programmed to emit at 4,000K. As the designer intended, there was no dynamic change of light intensity and colour changes. See Figure 4.18 for the mounting positions of light sources and a general view of the setting.

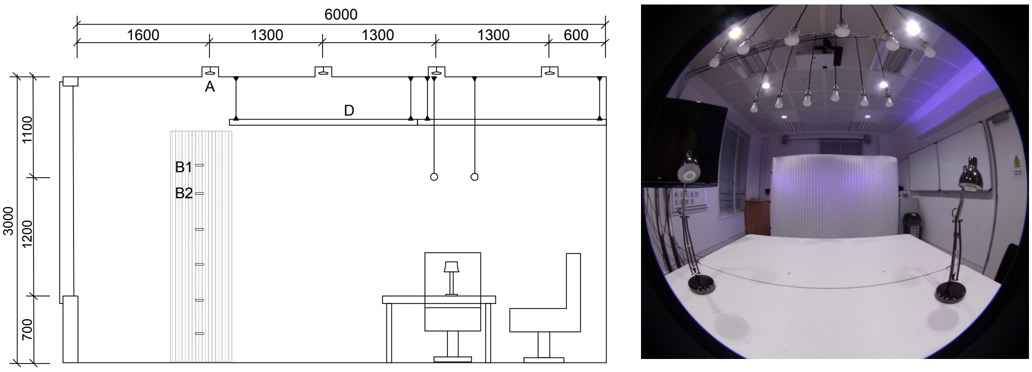


(a) A section drawing for lively setting 3 (b) A fisheye view

Figure 4.18. Lively setting 3 (a section drawing and a photograph)

Lively setting 4

A significant compromise was needed to replicate the lively concept 4. First, the designer originally suggested using the curved partition to surround the whole room, which was physically impossible due to the size of the partition. Instead, the partition only covered a part of the front view. As shown in Figure 4.19, two Philips Hue LED strips (B1 and B2) were mounted at the top of the partition to create similar a lighting pattern. All of the LED strips (B1, B2 and D) were set for saturated blue colour. There was no use of pendant lamps but the ceiling luminaires (A) were turned to 5,000K.

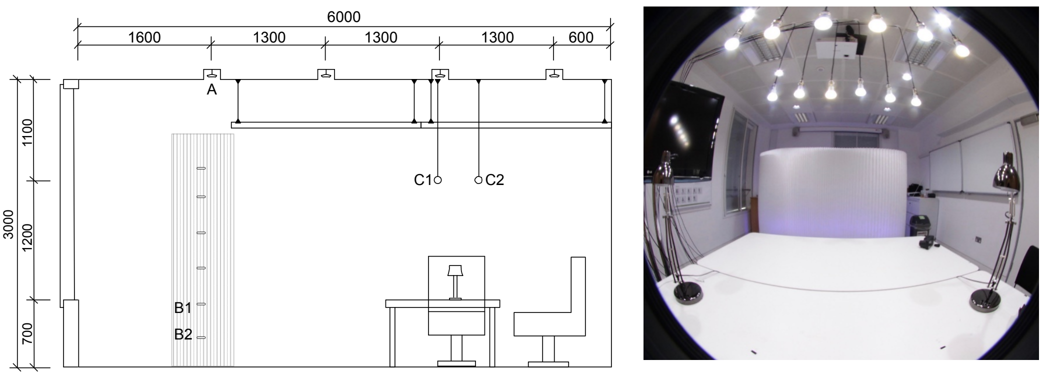


(a) A section drawing for lively setting 4 (b) A fisheye view

Figure 4.19. Lively setting 4 (a section drawing and a photograph)

Lively setting 5

The ceiling luminaires (A), two sets of Philips Hue LED strips (B1 and B2), and twelve pendant lamps (C1 and C2) were used for the replication of the lively concept 5. The ceiling luminaires were programmed to change color temperature from 4,000K to 6,500K in a slow loop (20 minutes) with 50% in intensity. Similar to the lively setting 1, the designer originally intended to put an array of GU10 lamps behind the partition for directional light patterns. Instead, two Philips Hue LED strips (B1 and B2) were mounted for creating a directional pattern. The LED strips were programmed to change their colour from cyan to saturated blue in a loop of 5 minutes. Lastly, twelve pendant lights with Philips Hue A19 lamps (C1 and C2) were programmed to change their color temperature from 4,000K to 6,500K in a slow loop (20 minutes) while emitting 70% of intensity. Figure 4.20 shows a layout of used lighting fixture and a general view of the setting.



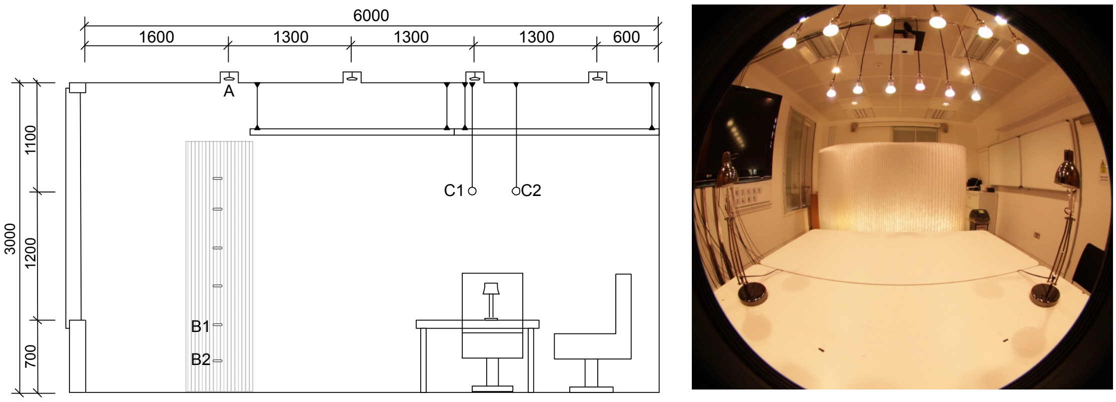
(a) A section drawing for lively setting 5 (b) A fisheye view

Figure 4.20. Lively setting 5 (a section drawing and a photograph)

4.4.3 'Relaxing' lighting settings

Relaxing setting 1

The relaxing concept 1 shares the same lighting design approach as the lively setting 1 except for the different use of colour in them. Two Philips Hue LED strips (B1 and B2) were programmed to change their colours from pastel tones of red, green and blue in a 5-minute loop. Six pendant lamps (C1) were programmed in the same way of the B1 and B2. The ceiling luminaires (A) were set to a constant 3,000K.

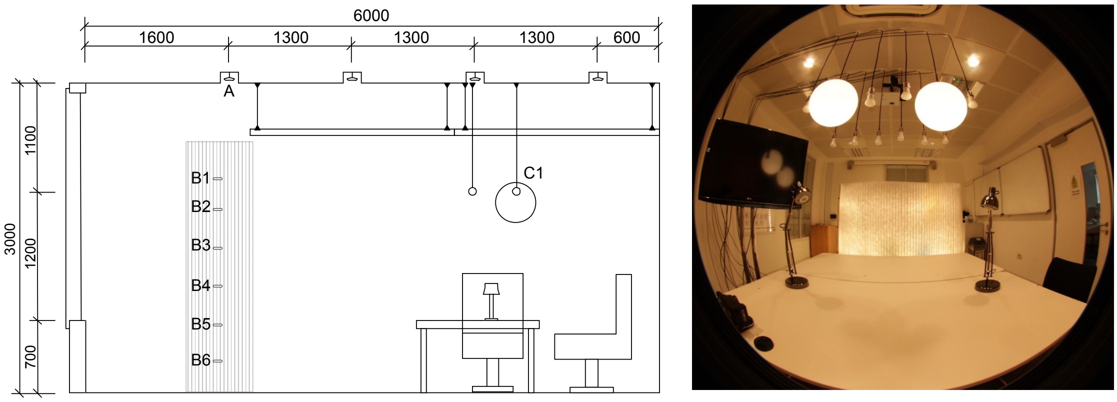


(a) A section drawing for relaxing setting 1 (b) A fisheye view

Figure 4.21. Relaxing setting 1 (a section drawing and a photograph)

Relaxing setting 2

The designer originally intended to use only pendant lights (with the lamp shade) and the self-luminous partition for relaxing concept 2. However, due to a shortable of the lamp shades, the designer allowed the use of a weak level of lights from the ceiling luminaires. Therefore, the ceiling luminaires (A) were set for 3,000K. All of the other light sources in this setting were set for 3,000K with no change in colour and intensity.

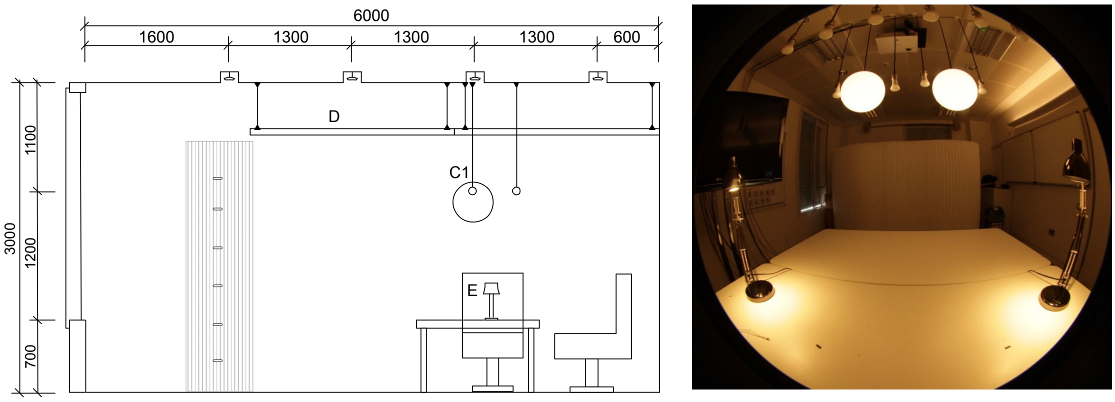


(a) A section drawing for relaxing setting 2 (b) A fisheye view

Figure 4.22. Relaxing setting 2 (a section drawing and a photograph)

Relaxing setting 3

The table lamps (E, Philips Hue A19 lamps) were used for the main source of task lighting as the designer originally suggested in the relaxing concept 3. The wall lighting (D, Philips Hue LED strip) and the pendant lights (C1) were all set for 2,700K to create a warm colour appearance to match by the designer's intention.

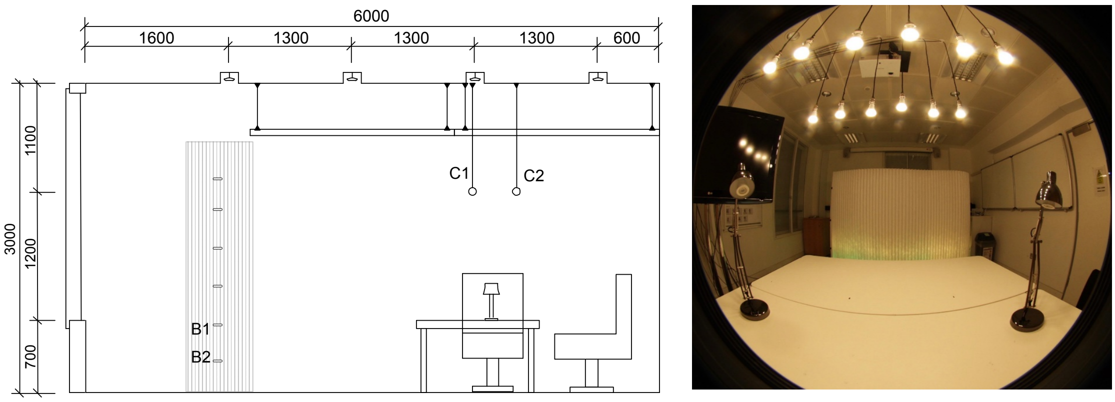


(a) A section drawing for relaxing setting 3 (b) A fisheye view

Figure 4.23. Relaxing setting 3 (a section drawing and a photograph)

Relaxing setting 4

The main source of task lighting for the relaxing setting 4 were the pendant lights (Philips Hue A19 lamps). Two Philips LED strips (B1 and B2) were mounted inside the translucent partition and were programmed to change colour properties from saturated yellow colour to a neutral white colour (4,000K) in a 5-minute loop. The Philips Hue A19 lamps (C1 and C2) were set for 2,700K and no additional lighting was provided from either the ceiling luminaires or table lamps.

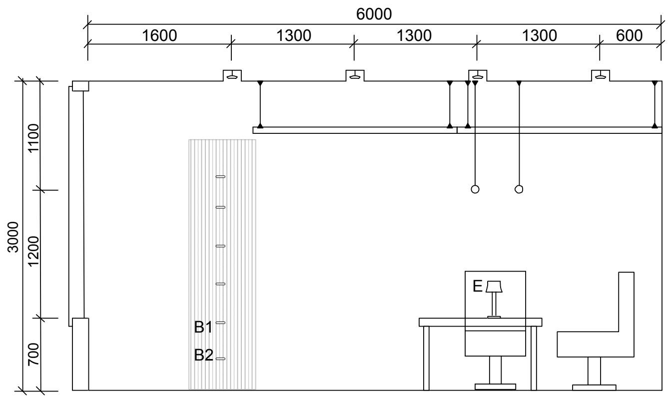


(a) A section drawing for relaxing setting 4 (b) A fisheye view

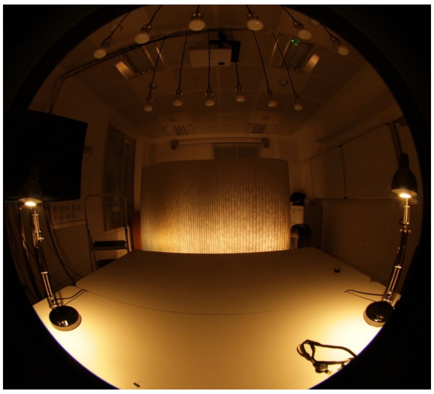
Figure 4.24. Relaxing setting 4 (a section drawing and a photograph)

Relaxing setting 5

Lastly, the relaxing concept 4 was replicated and its layout of the lighting fixture is shown in Figure 4.25(a). Although the designer originally intended to create a narrow directional light pattern on each of the side of walls, a compromise was made due to the resource limitation. Instead, two Philip Hue LED strips were mounted inside the partition (See Figure 4.25(b)) and created a directional light pattern on the partition surface. Apart from the LED strips, two table lamps (Philips Hue A19) were used for the main task lighting. All of the lights in this setting were set at 2,700K.



(a) A section drawing for relaxing setting 5



(b) A fisheye view

Figure 4.25. Relaxing setting 5 (a section drawing and a photograph)

After looking at the ten converted light settings, the study has summarised the differences between the ten original concepts and the ten replicated settings, which is shown in Table 4.6.

Table 4.6. Differences between the original concepts and the replicated settings

	Differences between the original concepts and the replicated settings
Lively 1	• In the concept, a directional effect (uplight) was created on the self-luminous wall partition by putting an array of GU10 bulbs in behind. • In the setting, a directional effect was created on the self-luminous wall partition by mounting an LED strips inside the partition. • In the concept, the curved self-luminous partition covered large part of the room. • In the setting, the coverage of the curved self-luminous partition was limited. • In the concept, floor lamps, pendant lights, ceiling lights are used. • In the setting, the use of floor lamps was excluded.
Lively 2	• In the concept, four pendant lights with the lampshade was suggested. • In the setting, two pendant lights with lampshade was provided. • The shape of the lampshade is slightly unmatched between the concept and the setting.
Lively 3	• In the concept, there was no presence of the curved partition in the room. • In the setting, there was a presence of the curved partition in the room but not as a form of self-luminous one. • In the concept, wall lighting created a lighting effect that can be seen on both side walls. • In the setting, only one side wall was equipped with the wall lighting. Therefore, an effect was only visible in one side of the walls.
Lively 4	• In the concept, the curved partition completely covers the surrounding walls • In the setting, the curved partition covers limited areas of the field of view. • In the concept, there was no presence of pendant lighting • In the setting, the pendant lighting system was mounted (not in use).
Lively 5	• In the concept, a directional effect (uplight) was created on the self-luminous wall partition by putting an array of GU10 bulbs in behind. • In the setting, a directional effect (uplight) was created on the self-luminous wall partition by mounting an LED strips inside the partition.
Relaxing 1	• The same as 'Lively 1' in this table
Relaxing 2	• The same as 'Lively 2' in this table
Relaxing 3	• The same as 'Lively 3' in this table.
Relaxing 4	• The same as 'Lively 4' in this table.
Relaxing 5	• In the concept, there were floor corner uplighters (GU10 bulbs). • In the setting, an LED strip was mounted in the curved partition to create a directional effect (uplight), and no corner uplighter was presented.

4.4.4 'Miscellaneous' lighting settings

The lighting designers' perspective of a lively and relaxing workspace were explored and replicated into actual light settings. However, before the measurement of photometric and colorimetric characteristics of each setting, the author added five additional 'miscellaneous' settings. The rationale for the miscellaneous settings was to test the impact of lighting (both illuminance level and CCT) on human psychological responses drawn from many studies in the previous literature. Since all of the ten designers' inspired settings were not built based on the scientific findings but instead designers' experience and insight, having these extra miscellaneous settings based on scientific findings would enable the author to compare and analyse the results among the settings.

In total, five miscellaneous settings were added, which are referred to as miscellaneous setting 1 to setting 5. The first miscellaneous setting (miscellaneous setting 1) was designed with the intention of evoking a high level of activation. A number of researchers such as Küller and Wetterberg (1994), Boulos *et al.* (1995), Küller *et al*. (2006), Viola *et al.* (2008), and Walmsley *et al.* (2015) have suggested that a high level of illuminance (on the working plane) and cool white light sources (compared to warm white light sources) were the variables that influence human activation level. Based on such literature miscellaneous setting 1 was set for both high illuminance and high CCT value (6,500K). To compare with miscellaneous setting 1, miscellaneous setting 2 was set for a high illuminance level but with a low CCT value (2,000K). Miscellaneous setting 3 and 4 were also paired like the above settings but with a relatively low light level. To achieve this the overhead light sources (the ceiling luminaires, and the pendant lamps) were excluded in these settings. Only the table lamps, the self-luminous partition and wall lighting were provided to investigate the impacts of correlated colour temperatures (2,000K vs. 6,500K) under relatively less bright workspace environment. Lastly, miscellaneous setting 5 was intended to provide the highest level of contrast in colour appearance in the field of view. The hypothesis was that having a high contrast colours in the field of view would result in the perception of high visual interest. The author has drawn the circumplex affect model and marked hypothesized emotional responses under the five miscellaneous settings as shown in Figure 4.26. The figure also shows expected responses of 'lively' and 'relaxing' settings. Explanations of details on lighting fixture layout of each miscellaneous setting follows.

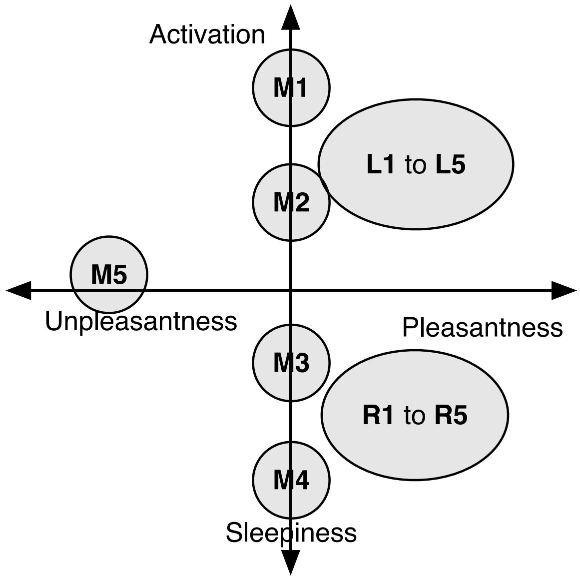
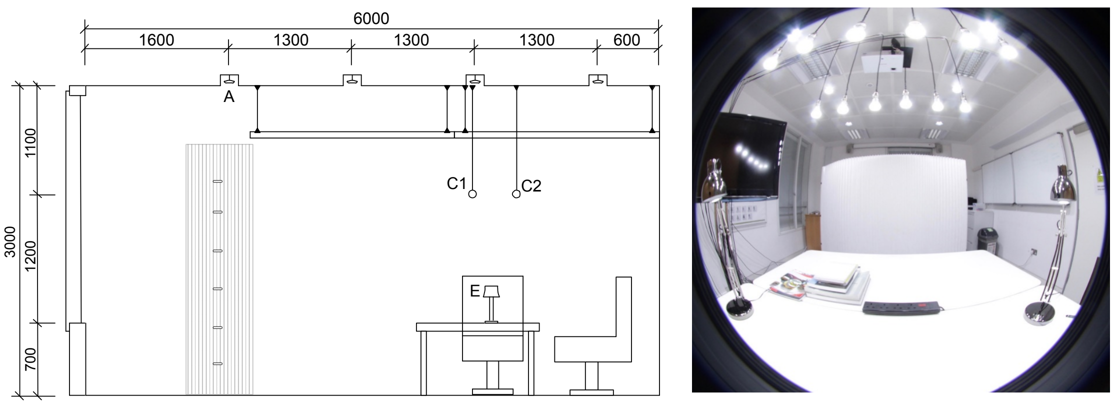


Figure 4.26. Hypothesized emotional responses under the fifteen light settings

<u>Miscellaneous setting 1</u>

As shown in Figure 4.27(a), the ceiling luminaires (A) and twelve pendant lights (C1 and C2, Philips Hue A19 lamps) were used. Additionally, two table lamps (E, Philips Hue A19 lamps) were also turned on to maximize illuminance levels on the task area. All of the lights in this setting were set for 6,500K, which was highest possible setting provided by the manufacturers. A general view of the setting is shown in Figure 4.27(b).

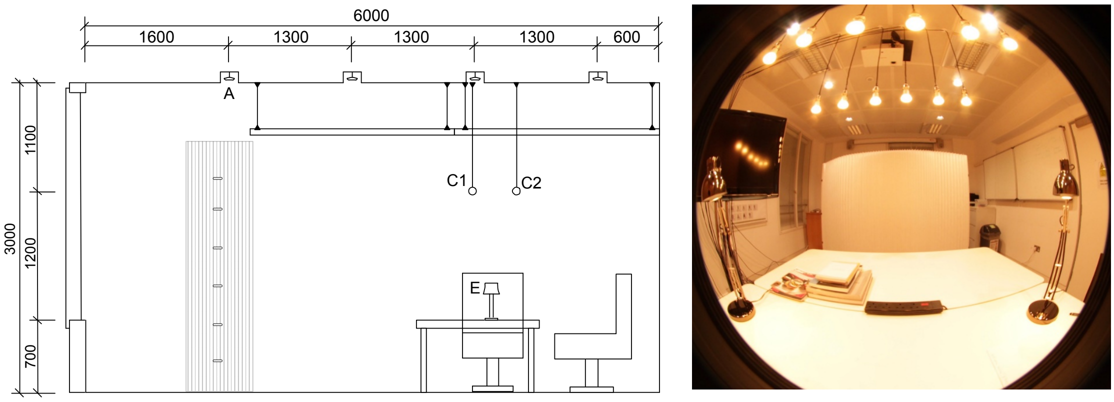


(a) A section drawing for miscellaneous setting 1 (b) A fisheye view

Figure 4.27. Miscellaneous setting 1 (a section drawing and a photograph)

Miscellaneous setting 2

As shown in Figure 4.28(a), the same lighting fixtures were applied for miscellaneous setting 2. All of the used light sources were set to 2,000 – 2,500K. A minor difference of CCT between the ceiling luminaires (set for 2,500K) and the table lamps (set for 2,000K) was due to the limited control ranges. As shown in Figure 4.28, the overall light setting was identical to miscellaneous setting 1 apart from the colour appearance.

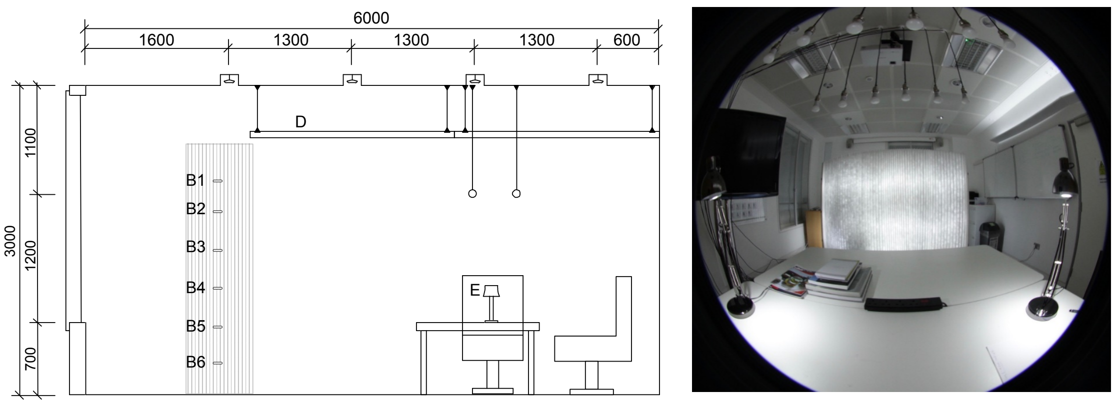


(a) A section drawing for miscellaneous setting 2 (b) A fisheye view

Figure 4.28. Miscellaneous setting 2 (a section drawing and a photograph)

Miscellaneous setting 3

As mentioned above, the objective of miscellaneous setting 3 was to provide cool-white colour appearance under a relatively lower light level compare to the previous two settings. Therefore, as shown in Figure 4.29(b), two table lamps (Philips Hue 19 lamps), were used for the main task lighting. The wall lighting, and the self-luminous wall were also used for additional source of lights. All of the lamps used in the setting were set for 6,500K. There was no use of pre-programmed light sources that changed their colours or intensities over a time.

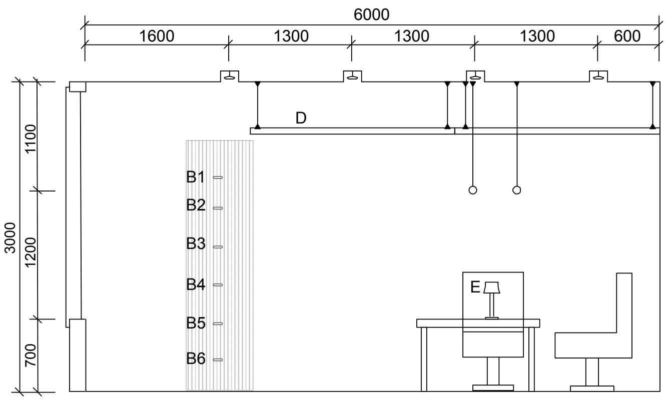


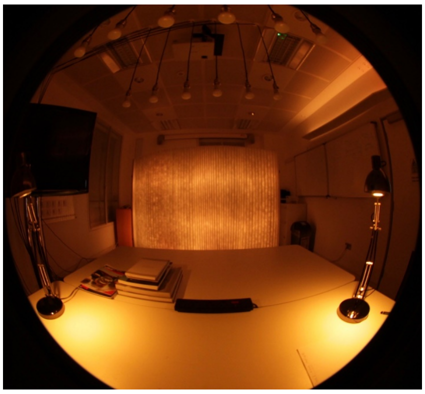
(a) A section drawing for miscellaneous setting 3 (b) A fisheye view

Figure 4.29. Miscellaneous setting 3 (a section drawing and a photograph)

Miscellaneous setting 4

As explained earlier, miscellaneous setting 3 and setting 4 shared the same use of lighting fixtures. The difference was that all of the lamps in this setting were set for 2,000K and a general view of the setting is shown in Figure 4.30(b).



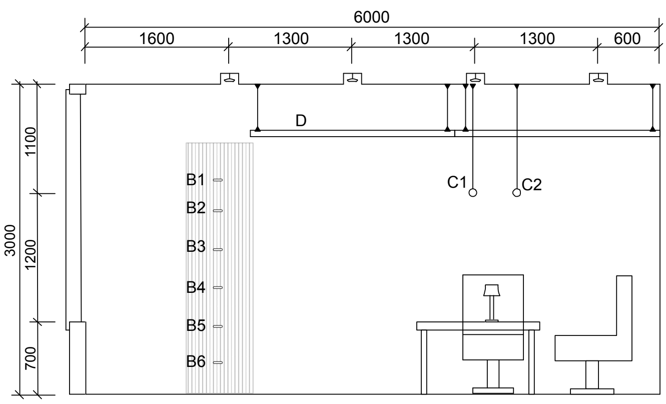


(a) A section drawing for miscellaneous setting 4 (b) A fisheye view

Figure 4.30. Miscellaneous setting 4 (a section drawing and a photograph)

Miscellaneous setting 5

Twelve pendant lights (C1 and C2, Philips Hue A19 lamps) in this setting were programmed to change colour properties from saturated blue, green to red in a 5-minute loop. Six Philips Hue LED strips were mounted inside the translucent partition and were programmed the same as the pendant lights. Also, the wall lighting was turned on and set for saturated Red colours. A general view of the setting is shown in Figure 4.31(b).



(a) A section drawing for miscellaneous setting 5 (b) A fisheye view

Figure 4.31. Miscellaneous setting 5 (a section drawing and a photograph)

In summary, the chapter has provided in-detail descriptions of five ‘lively’ and five ‘relaxing’ design concepts by reference to the content of the design brief, which was introduced in Chapter 3. Then, design analyses of both ‘lively’ and ‘relaxing’ concepts were followed. The chapter then explained a process of how the concepts are converted into the light settings. In order to strengthen the originality of the study, an additional five lighting settings, referred as ‘miscellaneous’ settings have been defined, and developed at the end of this chapter.

Chapter 5

Photometric and colorimetric characteristics of lighting settings

In total, fifteen light settings (five 'lively', five 'relaxing' and five 'miscellaneous') were configured in the previous chapter. This chapter first introduces the main parameters that were used to describe luminous environments of each setting and then explains their photometric and colorimetric characteristics.

5.1 Parameters

5.1.1 Illuminance and uniformity

Horizontal illuminance (working plane height)

According to several codes and lighting recommendations, the illuminance and its distribution on the task area and on the immediate surrounding area have a great impact on how quickly, safely and comfortably a person perceives and carries out the visual task (SLL, 2012; Committee of European Standards, 2011). Therefore, horizontal illuminance values at the height of working task plane (0.8m) were measured (based on the guidance from SLL (2012)). Figure 5.1 shows the illuminance grid (coded 1 to 8 and A to H) set by this study for the measurement. Each square has a dimension of 500mm×500mm as shown in Figure 5.1 and the measurement took place at the centre of each square.

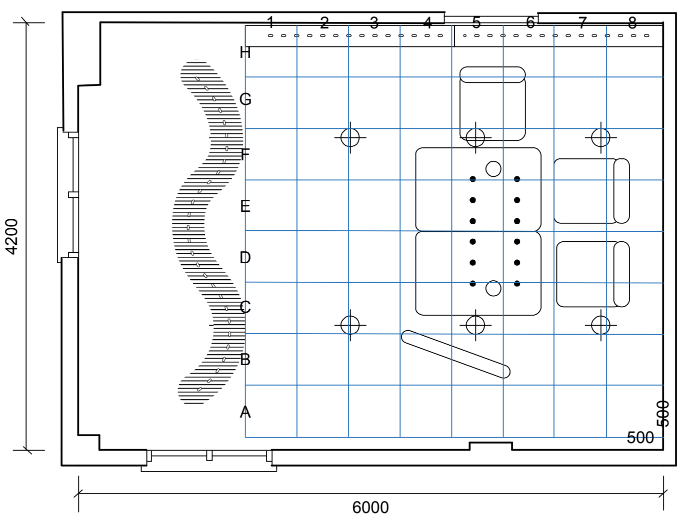


Figure 5.1. The illuminance grid (blue lines) plotted on the experimental area (0.8m height)

Spatial variation in the illuminances surrounding the task area should be considered important as it could lead to visual stress and discomfort (Pellegrino, 1999). The Code defines the immediate surrounding area as a band with a width of at least 0.5m around the task area in the visual field (SLL, 2012). Based on the above information, the study defined a task area, an immediate surrounding area and the background area, which is shown in Figure 5.2. Illuminances were measured for each defined area under the fifteen light settings.

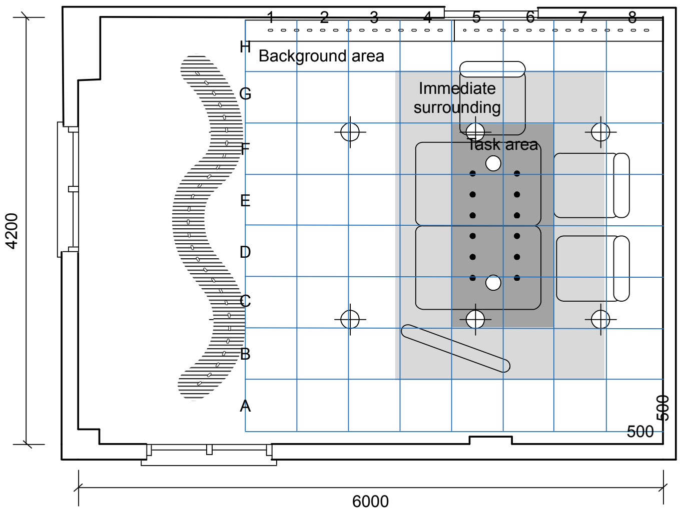
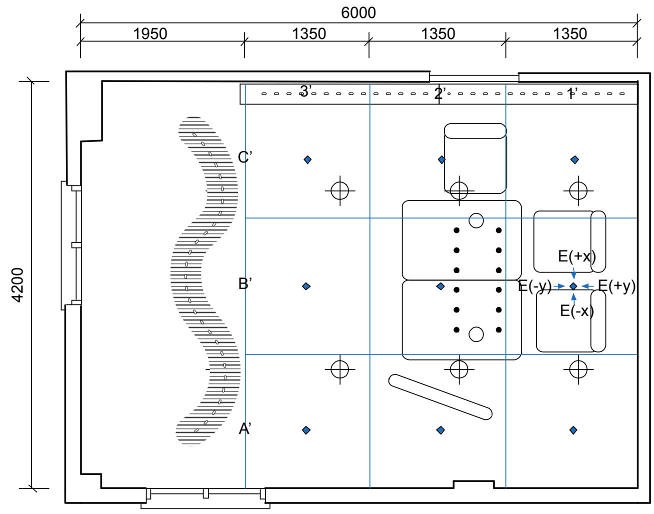


Figure 5.2. A defined task area, an immediate surrounding area and a background area Illuminance measurements were recorded in the centre of each square marked by the blue grid.

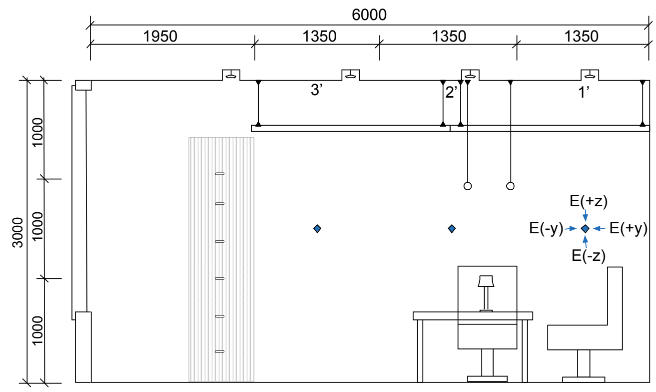
<u>Mean cylindrical illuminance</u>

The volume of space that is occupied by people should be lit in order to highlight objects, reveal texture and improve the appearance of people within the space (SLL, 2012). This is satisfied by providing an adequate level of mean cylindrical illuminance in the activity space. Cylindrical illuminance is defined as the *total luminous flux falling on the curved surface of a very small cylinder located at a specified point, divided by the curved surface of the cylinder* (SLL, 2012). In order to obtain cylindrical illuminance values of each light setting, cubic illuminances were measured at 9 different points (coded 1' to 3' and A' to C') at the height of 1.4m, as shown in Figure 5.3.

Cubic illuminance is *the specification of the directional distribution of incident luminous flux at a point in space, in terms of pairs of opposed planar illuminances, normal to three mutually perpendicular axes intersecting a certain point* (Cuttle, 1997). Simply speaking, it is the illuminance falling on the six faces of an infinitely small cube, as shown as E(+x), E(-x), E(+y), E(-y), E(+z) and E(-z) in Figure 5.3(a) and 5.3(b).



(a) Floor plan showing cubic illuminance measurement points



(b) Section plan showing cubic illuminance measurement points

Figure 5.3. 9 points of cubic illuminance measurement (height: 1.4m)

Note: Blue diamond indicates the measurement points

In order to calculate a cylindrical illuminance at a point, the vector ('E) and the symmetric (~E) components were first calculated by using the following equations (5.1) – (5.8).

$$'E_{(x,y,z)} = ('E_{(x)}, 'E_{(y)}, 'E_{(z)}) \quad \text{Equation (5.1)}$$

$$'E_{(x)} = E_{(+x)} - E_{(-x)} \quad \text{Equation (5.2)}$$

$$'E_{(y)} = E_{(+y)} - E_{(-y)} \quad \text{Equation (5.3)}$$

$$'E_{(z)} = E_{(+z)} - E_{(-z)} \quad \text{Equation (5.4)}$$

$$\sim\mathrm{E}_{(x,y,z)} = (\sim E_{(x)}, \sim E_{(y)}, \sim E_{(z)}) \quad \text{Equation (5.5)}$$

$$\sim E_{(x)} = min(E_{(+x)}, E_{(-x)}) \quad \text{Equation (5.6)}$$

$$\sim E_{(y)} = min(E_{(+y)}, E_{(-y)}) \quad \text{Equation (5.7)}$$

$$\sim E_{(z)} = min(E_{(+z)}, E_{(-z)}) \quad \text{Equation (5.8)}$$

The symmetric component of the vector is the quantity of light that is equally received on each side of the cube and the vector components are the differences between each pair of opposite sides of the cube (Cuttle, 1997; Cuttle, 2015). From the above values and using equations (5.9) – (5.13), cylindrical illuminance at a point was calculated. Aside from a cylindrical illuminance, a scalar illuminance (E_{sr}), which is defined as *the average illuminance over the whole surface of a small sphere centered at a reference point* (Lynes *et al.,* 1966) was easily calculated from the above equations as E_{sr} is the sum of contributions from the vector and symmetric solid (see equation (5.14)).

$$\left|E_{(x,y,z)}\right| = \left({'E_{(x)}}^2 + {'E_{(y)}}^2 + {'E_{(z)}}^2\right)^{0.5} \qquad \text{Equation (5.9)}$$

$$e_{(x)} = \frac{'E_{(x)}}{\left|E_{(x,y,z)}\right|} \qquad \text{Equation (5.10)}$$

$$e_{(y)} = \frac{'E_{(y)}}{\left|E_{(x,y,z)}\right|} \qquad \text{Equation (5.11)}$$

$$e_{(z)} = \frac{'E_{(z)}}{\left|E_{(x,y,z)}\right|} \qquad \text{Equation (5.12)}$$

$$E_{cyl} = \frac{|E|e.e_{(x,y)}}{\pi} + \frac{\left(\sim\mathrm{E}_{(x)} + \sim\mathrm{E}_{(y)}\right)}{2} \qquad \text{Equation (5.13)}$$

$$E_{sr} = \frac{|E|}{4} + \frac{\sim\mathrm{E}_{(x)} + \sim\mathrm{E}_{(y)} + \sim\mathrm{E}_{(y)}}{3} \qquad \text{Equation (5.14)}$$

Lastly, cubic illuminances at eye levels of two seating positions (seating position A and B, see Figure 5.4) were measured (height: 1.2m). Two widely known indicators of modelling (E_{cyl}/E_{hor} and $\boldsymbol{E}/E_{sr}$) were calculated through the measured cubic illuminances.

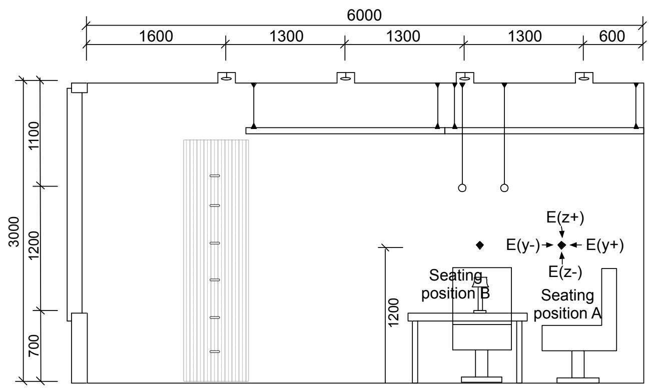


Figure 5.4. 2 points of cubic illuminance measurement (height: 1.2m)
Note: Black diamond indicates the measurement points

Illuminance on surfaces

There is a recommendation for all major surfaces to have a maintained illuminance. The SLL Code for lighting, for example, recommends that an indoor environment where visual communication is important should have higher level of illuminance on walls and ceilings than a normal enclosed space (SLL, 2012), which is shown in Table 5.1. Therefore, this study also measured illuminances on all the walls (left and right), the floor, and the ceiling. The measurement was conducted at 9 points (3 × 3 points) on each surface.

Table 5.1. Illuminance on room surfaces specified in the SLL Code for Lighting 2012

Illuminances in enclosed spaces	
Walls	$E_m > 50\ lx\ with\ U_o \geq 0.10$
Ceiling	$E_m > 30\ lx\ with\ U_o \geq 0.10$
Illuminances in enclosed spaces where visual communication is important	
Walls	$E_m > 75\ lx\ with\ U_o \geq 0.10$
Ceiling	$E_m > 50\ lx\ with\ U_o \geq 0.10$

All of the illuminance measurements were conducted using an illuminance meter, Konica Minolta T10-A, which is shown in Figure 5.5.

Figure 5.5. An illuminance meter (Konica Minolta T10-A)
Source: http://sensing.konicaminolta.asia/products/t-10a-illuminance-meter/

5.1.2 Luminance and luminance ratio

Average luminance (within the field of view)

Luminance and luminance ratio in the visual field is another parameter that is widely used for the assessment of the luminous environment. A number of lighting codes or standards state the importance of a well-balanced adaption luminance in a workspace (SLL, 2012).

Therefore, luminance and luminance ratio in the visual field were also measured at each light setting by the author. The luminance values were measured by a luminance measuring camera. The camera (Cannon EOS 60D with a Sigma 4.5mm f/2.8 HSH circular fisheye lens) created HDR luminance maps from a set of calibrated images with a 180° field of vision. Then, PHOTOLUX 3.2, a processing software, was used to make a luminance statistical analysis on the complete map or on a selected zone (see more details on the specification of the software at www.photolux-luminance.com). Figure 5.6 shows the luminance measuring camera and the software.

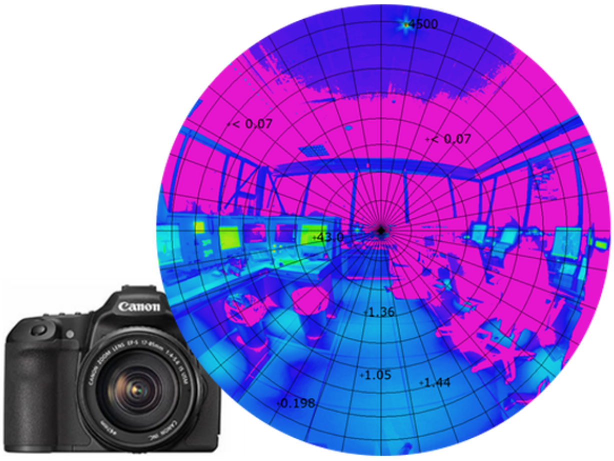


Figure 5.6. a luminance measuring camera and a mapping software
(Canon EOS 60D and PHOTOLUX 3.2)
Source: https://www.photolux-luminance.com/

In order to assess luminance ratio of the space (L_{max}:L_{min}), the study defined key surfaces within the field of view. First, the ceiling, the floor and the wall surfaces were first identified. Although the floor of the room is an important surface, a view to the floor was obstructed by the task table. Therefore, although the luminance on the floor surface was measured, the values were excluded in the calculation of luminance distribution within the field of view. The walls were divided into three surfaces: left, right and front wall (see Figure 5.7). However, the view to the front wall was largely covered by the partition. Therefore, luminance value on the partition was used instead of the front wall. Lastly, in the room, there was a table and the table area was divided into two surfaces, task area and surrounding task area. In summary, in relation with luminance and luminance ratio calculation, the surfaces in the room were divided into six areas of the left wall, the right wall, the partition (instead of the front wall), the ceiling, the task area, and the surrounding task area.

Loe *et el.* (1994) suggested there is a relationship between average luminance of the horizontal band of width 40° at viewer's eye level, which was defined as $L_{av}\ (B40)$ and perception of 'visual lightness'. An indication of extent of 40° horizontal band is shown in Figure 5.7. According to their finding, it could be assumed that the assessment of subjective perception of 'visual lightness' changes from generally dim to generally bright, corresponds to a value of approximately 30 cd/m^2 on the L_{av} $(B40)$. More specifically, their study suggested that a perception of dim to a perception of having a degree of visual lightness seems to occur at 30 cd/m^2 of L_{av} $(B40)$. They also found that the ratio of the maximum luminance to the minimum luminance in the 40^o wide horizontal band, L_{max}:L_{min} $(B40)$ was related with perception of 'visual interest' and it could be assumed that the assessment of lit environment changes from generally uninteresting to have a degree of visual interest, relates to a value of approximately 13 as the ratio of L_{max}:L_{min} $(B40)$. However, this study differed many ways from the study from Loe *et al.* (1994). In Loe *et al.*'s study, participants stood at the corner of the experimental space and assessed their visual perception of a space, whereas in this study, participants sat on a chair and accessed their psychological perception and moods as shown in Figure 5.7. In order to verify Loe *et al.'s* suggestion in this study, with the different research design, L_{av} $(B40)$ the extent of 40° horizontal band was indicated in this study, which is shown in Figure 5.7.

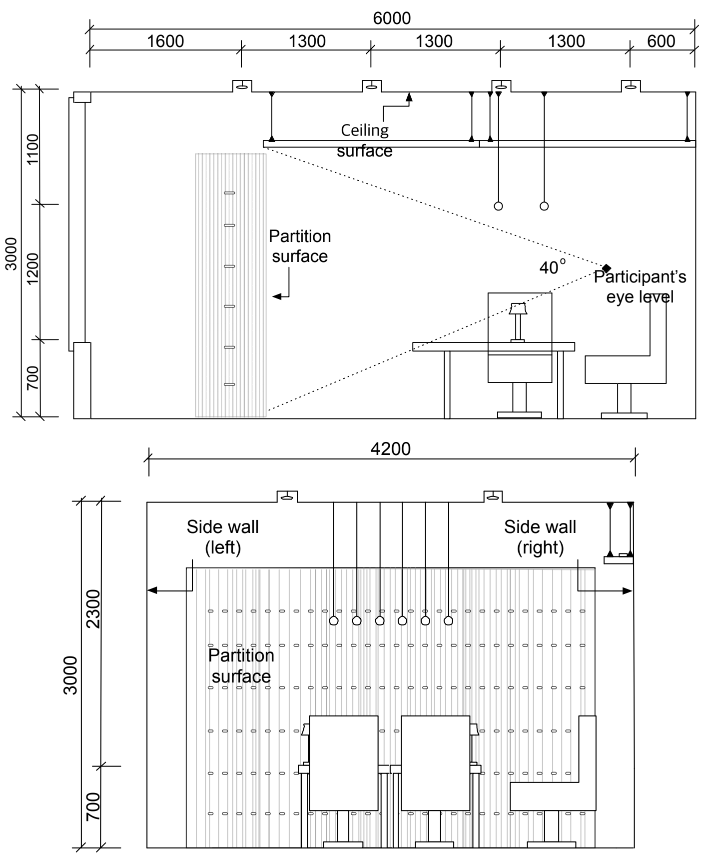
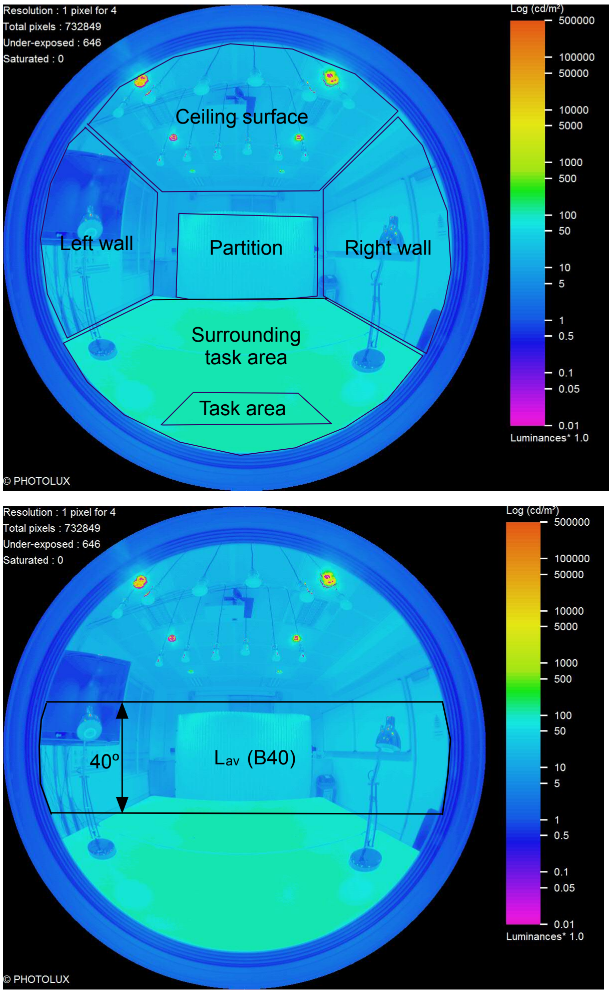


Figure 5.7. Defined the key surfaces in section views (within the field of view)

As can be seen from the figure, B40 in this study corresponds to the area including side walls (both left and right) and the partition.

Figure 5.8 shows an example of luminance map of the light settings within the field of view. The study created six zones in the luminance map to match the defined surface areas. When calculating the average luminance on each defined zone, the light sources were excluded.



Defined six zones in the luminance map:

1) Task area
2) Surrounding task area
3) Partition
4) Ceiling surface
5) Left wall
6) Right wall

Figure 5.8. Defined six zones in respect to the defined surfaces in the luminance map

5.1.3 Mean room surface exitance (MRSE)

As reviewed in Chapter 2, Cuttle (2010) has argued that perceived adequacy of illuminance is a key criterion for any well-lit room. He has related that to the mean room surface exitance (MRSE) of the room. To give a definition again for MRSE, it is defined as '*the measure of average* *illuminance of all points within a space due to reflected light from the room surfaces, with direct light from either the luminaires or windows excluded (Cuttle, 2010)*'.

Using a reasonable assumption that all surfaces within a space are Lambertian diffusers, MRSE can be defined by the sum of the area-weighted exitance values within a space, divided by the total room surface area (Duff, 2016). Since this study measured either luminance or illuminance on most of the key surfaces of the experimental room, MRSE for each setting was calculated through following equations ((5.15) to (5.17)).

$$MRSE = \frac{\sum M_s A_s}{\sum A_S} \quad \text{Equation (5.15)}$$

$$M_s = L_s \pi \quad \text{Equation (5.16)}$$

$$M_s = E_s \rho_s \quad \text{Equation (5.17)}$$

Where M_s is the mean exitance of each surface within the space, A_s is the area of each surface and ρ_s is a reflectance value of each surface. The mean surface luminance, L_s and the mean surface illuminance, E_s (Duff, 2016; SLL 2012) are used to calculate MRSE of each setting.

Based on the above equations, the study was able to calculate the reflected amount of light of most of the key surfaces within the experimental room. Although several interior fittings such as a TV stand were excluded and a few assumptions were made for determining the reflectance values of some surfaces in the calculation process, it is believed that the MRSE values calculated from the above equations were reliable to report. Table 5.2 summarises the area size of each surface used in this process.

Table 5.2 Areas of the key surfaces within the experimental room

	Area (m^2)
Left wall surface	18
Right wall surface	18
Front wall surface	12.8
Partition surface	5.4
Ceiling surface	25.2
Floor surface*	22.32*
Back-front wall surface**	12.8**
Task table surface	2.88
Sum of the surfaces	117.4

*Reflectance of the floor was assumed as 0.2 (Dark carpet)

**Reflectance of the back-front wall surface (room divider) was assumed as 0.5

5.1.4 Colour aspects

The colour qualities of each light setting were also measured. One difficulty with regard to the colour aspects in this study is that a number of light settings involved dynamic components of luminous environments. This study therefore only considered two attributes of colour aspects; the colour appearance of the light, and its colour rendering capabilities. There is no specific guideline or recommendation for using a certain colour appearance in a workspace but rather it is a matter of psychology, aesthetics (SLL, 2012). Correlated colour temperature (CCT) at a viewer's eye level was measured to represent the colour appearance of the light. To provide an objective indication of the colour rendering properties of a light source the general colour rendering index (R_a) was also measured at the same point. The measurement of colour aspects were conducted with an illuminance spectrophotometer, Konica Minolta CL-500A, which is shown in Figure 5.9. All of the devices used in this study (Konica Minolta CL-500A, Cannon EOD 60D with the Photolux, and Konica Minolta T10A) were purchased within 1 years (at the point of using them) and therefore were still under the manufacturers' guarantee of their calibration qualities.

Figure 5.9. An illuminance spectrophotometer (Konica Minolta CL-500A)
Source: http://sensing.konicaminolta.us/products/cl-500-illuminance-spectrophotometer/

5.2 Characteristics of 'lively' settings

5.2.1 Lively setting 1

Illuminance and illuminance uniformity

Measured and calculated illuminances and their uniformity (horizontal illuminance, illuminances on major surfaces, mean cylindrical illuminance, vertical illuminance and modelling indicator) at lively setting 1 were summarised in Table 5.3. As can be seen from Table 3, lively setting 1 achieved all of the criteria set by European Standard (BS EN 12464-1) and the SLL Code for lighting. Due to high mean cylindrical illuminance (243 lx), this setting could be suitable for a task that involves a substantial amount of visual communication. Also, calculated values of the modelling index suggested the lighting would provide a strong flow of light.

Table 5.3 A summary of illuminance and illuminance uniformity at lively setting 1

Horizontal illuminance (h: 0.8m)	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	760(≥750)	0.72(≥0.7)
Immediate surrounding area	654(≥500)	0.64(≥0.4)
Background area	531(33%of task area)	0.34(≥0.1)
Illuminances on surfaces		
Wall (left)	210(≥75)	0.17(≥0.1)
Wall (right)	275(≥75)	0.28(≥0.1)
Ceiling	201(≥50)	0.34(≥0.1)
Mean cylindrical illuminance (h:1.4m)	(E_{cyl}, lx)	Uniformity (E_{min}/E_{max}, U_o)
The whole measurement area	243 (≥ 150)	0.40(≥0.1)
Vertical illuminance (eye level)		480
Indicator of modelling (h:1.2m)		
$E_{cyl}/E_{horizontal}$		0.30 (0.3 to 0.6)
$\boldsymbol{E}/E_{sr}$		2.16 (1.2 to 1.8*)

Note: values in brackets indicates the recommended level set by European Standard, EN12464-1:2011
*Within the range of 1.2 to 1.8 is suggested to be preferred (Cuttle *et al.,* 1967; Protzman and Houser, 2015)

Measured illuminance and illuminance uniformity values suggests that lively setting 1 would be suitable for most office activities. Aside from illuminances, luminance and luminance distribution were also measured and calculated. Figure 5.10 shows the luminance map of lively setting 1 produced by PHOTOLUX 3.2. Average luminance in each defined zone (see Figure 5.8) was calculated as well as luminance distribution ($L_{max}/L_{min},$), which is summarised in Table 5.4. Neither the European standard nor the SLL Code for Lighting suggests a specific value of luminance or luminance distribution ratio for a luminous environment. Instead, European standard (EN 12464-1) states that too high or too low luminances should be avoided as they could either give rise to glare or result in a dull and non-stimulating working environment.

Luminance and luminance distribution

As can be seen from Table 5.4, average luminance of the horizontal band of width 40° (L_{av} $(B40)$ was 71 cd/m^2 and when the surrounding task area is included in the calculation, then the value increase by 80 cd/m^2. The luminance ratio of (L_{max}/L_{min}) was 4.3. Based on these values, it could be assumed that the space provokes an impression of 'generally bright' and 'generally uninteresting' (Loe *et al.,* 1994).

Table 5.4 A summary of luminance and luminance ratio at lively setting 1

Average luminance in the field of view	Average luminance, ($L_{av}, cd/m^2$)
L_{av} (whole surfaces in the room)	164
L_{av} $(B40)$	71 (>30*)
L_{av} ($B40$ + surrounding task area)	80.0
Average luminance on the six surfaces	Average luminance, ($L_{av}, cd/m^2$)
Left wall	47
Right wall	61
Ceiling	45
Task area	196
Surrounding task area	183
Partition	106
Luminance ratio (L_{max}/L_{min})	
L_{av} $(task\ area)$: L_{av} $(ceiling)$	196:45 = 4.3:1 (<13:1**)

*values over 30 cd/m^2 could be assumed to change a perception generally dim to a perception that has a degree of 'visual lightness' (Loe *et al.,* 1994).
**values above 13 could be $L_{av}L_{av}$ assumed to change a perception generally uninteresting to a perception that has a degree of 'visual interest' (Loe *et al.,* 1994).

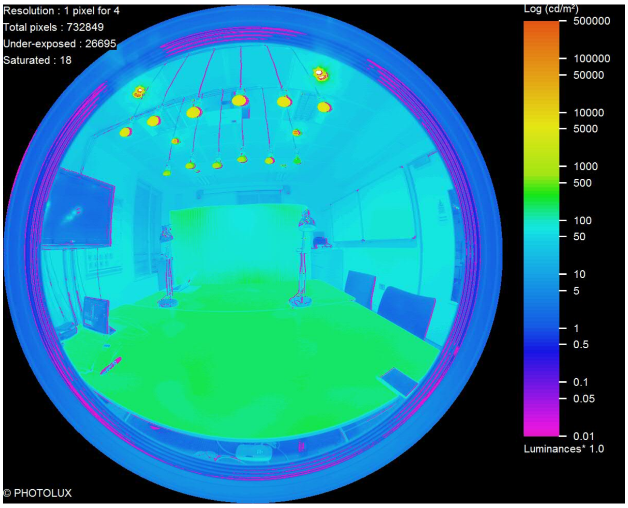


Figure 5.10. The luminance map (lively setting 1)

MRSE and colour aspects

Table 5.5 summarises the calculations of exitance of each surface. The calculation was conducted using equations (5.15) to (5.17). As a result, MRSE = 154 lm/m^2 was calculated for lively setting 1. According to Cuttle (2015), the room could appear between 'acceptably bright (MRSE=100 lm/m^2)' to 'bright appearance (MRSE=300 lm/m^2)'.

Table 5.5 A summary on calculation of MRSE (lively setting 1)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s, lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	45	-	25.2	0.8	3561
Wall (left)	47	-	18	0.7	2656
Wall (right)	61	-	18	0.7	3448
Wall (front)	30	-	12.8	0.7	1206
Wall (back)	-	198	12.8	0.5	1270
Floor	-	551	22.32	0.2	2460
Task table	183	-	2.88	-	1655
Partition	106	-	5.4	-	1797
		Sum	117.4		18052
				MRSE	**154**

Both correlated colour temperature (and CIE general colour rendering index (R_a) at a viewer' eye level was also measured and the values were CCT of 4,002K and R_a of 92 respectively. According to European standard (EN 12464-1), a user under this setting would perceive 'intermediate' colour appearance, being neither cool nor warm.

5.2.2 Lively setting 2

Illuminance and illuminance uniformity

Again, illuminances and illuminance uniformity under lively setting 2 were measured and calculated, which is summarised in Table 5.6. Average illuminance values on the task area, immediate surrounding area and background area show that this setting meets the recommendations set for most office-related tasks (except for technical drawing, which requires 750 lx). In terms of uniformity, the setting seems lightly lower than suggested recommendation levels. However, measured illuminance on surfaces and mean cylindrical illuminance achieved higher than the recommendation levels.

Table 5.6 A summary of illuminance and illuminance uniformity at lively setting 2

Horizontal illuminance		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	640(≥500)	0.43(≥0.6)
Immediate surrounding area	413(≥300)	0.36(≥0.4)
Background area	251(33%of task area)	0.29(≥0.1)
Illuminances on surfaces		
Wall (left)	170(≥75)	0.28(≥0.1)
Wall (right)	211(≥75)	0.32(≥0.1)
Ceiling	264(≥50)	0.10(≥0.1)
Mean cylindrical illuminance		
	Average illuminance ($E_{cyl},\ lx$)	Uniformity ($E_{min}/E_{max},\ U_o$)
The whole measurement area	275.5(≥ 150)	0.16(≥0.1)
Vertical illuminance (eye level)		740
Indicator of modelling		
$E_{cyl}/E_{horizontal}$		0.65 (0.3 to 0.6)
$\boldsymbol{E}/E_{sr}$		1.90 (1.2 to 1.8)

Note: values in brackets indicates the recommended level set by European Standard, EN12464-1:2011

Luminance and luminance distribution

Luminance and luminance distribution of luminous environment under lively setting 2 were also measured, which is summarized in Table 5.7. The luminance map generated by PHOTOLUX 3.2 is also presented in Figure 5.11. As can be seen from Table 5.7, average luminance of the horizontal band of width 40°, $L_{av}\ (B40)$ was 74 cd/m^2. Again, this lit environment could be assumed to be perceived as bright based on the above values.

The ratio of the maximum and the minimum luminance (of a surface) was 5, which shows a slight increase compared to lively setting 1. Since there was no use of the ceiling luminaires, the average luminance of two light sources (bare pendant lights, and pendant lights with a lampshade) were also measured as 38,000 and 900 cd/m^2. Average luminance on the partition surface was 136 cd/m^2, which was higher than lively setting 1.

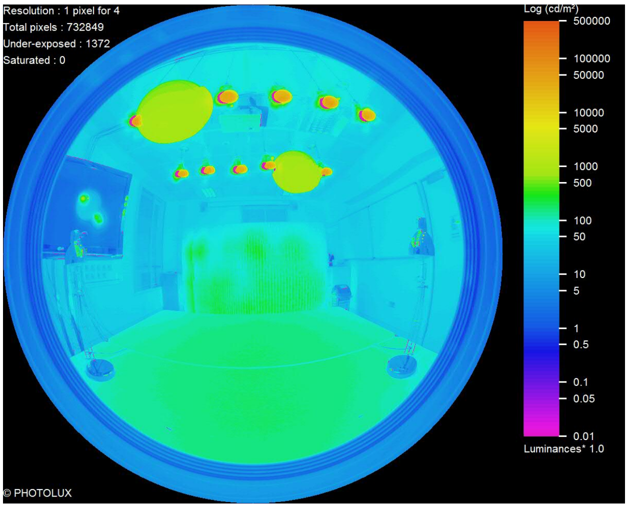


Figure 5.11. The luminance map (lively setting 2)

Table 5.7 A summary of luminance and luminance distribution at lively setting 2

Average luminance in the field of view	Average luminance, ($L_{av}, cd/m^2$
Average (whole surface + light sources)	237
Average (side walls + partition), $L_{av}\ (B40)$	74 (>30*)
Average (side walls + partition + task area)	103
Average luminance on each defined surface	
Wall (left)	38
Wall (right)	47
Ceiling	59
Task area	178
Surrounding task area	191
Partition	136
Luminance distribution	
L_{max}/L_{min}	191/38 =5 (>13**)

*values over 30 cd/m^2 could be assumed to change our perception of a room from generally dim to generally bright.

**values above 13 could be assumed to change our perception of a room from generally uninteresting to having a degree of visual interest.

<u>MRSE and colour aspects</u>

MRSE within the space under lively setting 2 was also calculated and its calculation process is summarized in Table 5.8. A value of 156.5 lm/m^2 was obtained from major surfaces within the space and such a value was very similar to the one obtained from lively setting 1. Based on this value, it could be assumed that the luminous environment would be perceived as between 'acceptably bright' and 'bright'. The measured CCT at a viewer's eye level was 4,039K and an 84 R_a=84 (CIE general colour rendering index) was observed, too. All of these values indicate that the space would provide a neutral (neither cool nor warm) colour appearance with an acceptable level of colour rendering quality.

Table 5.8 A summary on calculation of MRSE (lively setting 2)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s , lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	59	-	25.2	0.8	4669
Wall (left)	38	-	18	0.7	2148
Wall (right)	47	-	18	0.7	2656
Wall (front)	40	-	12.8	0.7	1608
Wall (back)	-	319	12.8	0.5	2039
Floor	-	274	22.32	0.2	1223
Task table	191	-	2.88	-	1727
Partition	136	-	5.4	-	2306
		Sum	117.4		18375
				MRSE	**156.5**

5.2.3 Lively setting 3

<u>Illuminance and illuminance uniformity</u>

Characteristics of measured illuminance and calculated illuminance uniformity were found to be substantially different from the ones obtained under the above two settings. First, average illuminance on the task area was much higher than the recommended level as shown in Table 5.9. Then a strong non-uniformity was observed regarding the spatial distribution of horizontal illuminance. Calculated uniformities were, in general, lower than the recommendation levels. In terms of illuminance on surfaces (walls and ceiling), values indicate that the surface receives less light than the previous settings but still meet the recommendation levels. A calculated modelling indicator suggests that a rendering quality (of nearby a person's face) might need improvement whereas the calculated mean cylindrical illuminance over the space with its uniformity was close to the recommendation. Based on the above parameters, although this space provides more than recommended light on the task area, the use of the space for a visual communication purposes might not be very suitable.

Table 5.9 A summary of illuminance and illuminance uniformity at lively setting 3

Horizontal illuminance		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	1116(≥750)	0.31(≥0.6)
Immediate surrounding area	397(≥500)	0.11(≥0.4)
Background area	113(33%of task area)	0.18(≥0.1)
Illuminances on surfaces		
Wall (left)	61.8(≥75)	0.48(≥0.1)
Wall (right)	100(≥75)	0.19(≥0.1)
Ceiling	117(≥50)	0.28 (≥0.1)
Mean cylindrical illuminance		
	Average illuminance ($E_{cyl},\ lx$)	Uniformity ($E_{min}/E_{max},\ U_o$)
Task + Immediate +background area	143.0(≥ 150)	0.09(≥0.1)
Vertical illuminance (eye level)		345
Indicator of modelling		
$E_{cyl}/E_{horizontal}$		0.69 (0.3 to 0.6)
$\boldsymbol{E}/E_{sr}$		2.03 (1.2 to 1.8)

Note: values in brackets indicates the recommended level set by European Standard, EN12464-1:2011

<u>Luminance and luminance distribution</u>

Luminance and luminance distribution under lively setting 3 were also found and summarized in Table 5.10. Again, the luminance map of luminous environment was provided, as shown in Figure 5.12.

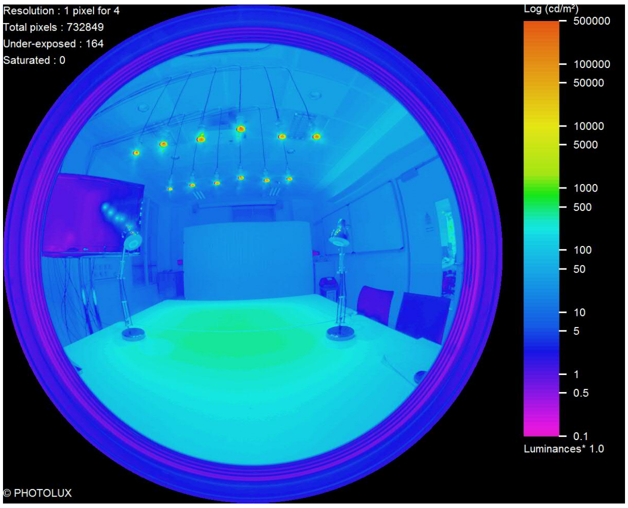


Figure 5.12. The luminance map (lively setting 3)

Here, luminance on the task area was much higher than the surrounding surfaces such as walls and ceilings and therefore the ratio of the maximum luminance and the minimum luminance was calculated as 16.2. Average luminance of the horizontal band of width 40º was only 22 cd/m^2 whereas average luminance on the task area was 223 cd/m^2. Such non-uniformity was matched by the results of the horizontal illuminance calculations. Based on the values, it could be assumed that the space would be perceived as 'dim' and 'visually interesting'.

Table 5.10 A summary of luminance and luminance distribution at lively setting 3

Average luminance in the field of view	Average luminance, $(L_{av}, cd/m^2)$
Average (whole surface + light sources)	101
Average (side walls + partition), $L_{av}\ (B40)$	22 (>30*)
Average (side walls + partition + task area)	72
Average luminance on each defined surface	
Wall (left)	13.8
Wall (right)	25.6
Ceiling	29.7
Task area	178
Surrounding task area	223
Partition	25.1
Luminance distribution	
L_{max}/L_{min}	223/13.8 =16.2 (>13**)

*values over 30 cd/m^2 could be assumed to change our perception of a room from generally dim to generally bright.
**values above 13 could be assumed to change our perception of a room from generally uninteresting to having a degree of visual interest.

MRSE and colour aspects

The use of narrow-beam pendant lights only for the main task area also influenced MRSE within the space. Table 5.11 shows the calculation processes of MRSE of the space under lively setting 3. A value of 74.1 lm/m^2 was calculated as a result and such a value does not meet the lowest level for 'acceptably bright' appearance set by Cuttle (2010). However, MRSE indicates the overall appearance of the space, which does not consider a seating position of a viewer. Since, a substantially high amount of light was provided and reflected from the task area, such a prediction might not be applicable for this case. Lastly, correlated colour temperature and CIE general colour rendering index were also measured and the values were 3,981K and R_a=85, respectively.

Table 5.11 A summary on calculation of MRSE (lively setting 3)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s , lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	30	-	25.2	0.8	2350
Wall (left)	14	-	18	0.7	780
Wall (right)	26	-	18	0.7	1447
Wall (front)	8	-	12.8	0.7	338
Wall (back)	-	130	12.8	0.5	833
Floor	-	114	22.32	0.2	508
Task table	223	-	2.88	-	2017
Partition	25	-	5.4	-	426
		Sum	117.4		8699
				MRSE	**74.1**

5.2.4 Lively setting 4

Illuminance and illuminance uniformity

Table 5.12 summarises the illuminance and illuminance uniformity that were measured and calculated from luminous environment under lively setting 4. Lively setting 4 shows a high level of uniformity in the spatial distribution of horizontal illuminance. Although the average illuminance was lower than 500 lx, the difference between the recommended value and the measured value was not great. Average illuminance on the walls and ceiling also indicate that the luminous environment meets the recommendation level for SLL Code for lighting. Mean cylindrical illuminance over the space seems slightly lower than the recommendation for an activity that requires much visual communication. Rendering of a neighbouring colleague's face would be acceptable according to the calculated modelling indicator. Out of the five lively settings, the highest level of uniformity in the spatial distribution of horizontal illuminance was observed under this setting.

Table 5.12 A summary of illuminance and illuminance uniformity at lively setting 4

Horizontal illuminance		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	416(≥500)	0.78(≥0.6)
Immediate surrounding area	349(≥300)	0.61(≥0.4)
Background area	302(33%of task area)	0.18(≥0.1)
Illuminances on surfaces		
Wall (left)	102(≥75)	0.31(≥0.1)
Wall (right)	140(≥75)	0.33 (≥0.1)
Ceiling	81(≥50)	0.54 (≥0.1)
Mean cylindrical illuminance		
	Average illuminance ($E_{cyl},\ lx$)	Uniformity ($E_{min}/E_{max},\ U_o$)
Task + Immediate +background area	125.2(≥ 150)	0.58(≥0.1)
Vertical illuminance		189
Indicator of modelling		
$E_{cyl}/E_{horizontal}$		0.32 (0.3 to 0.6)
$\boldsymbol{E}/E_{sr}$		1.74 (1.2 to 1.8)

Note: values in brackets indicates the recommended level set by European Standard, EN12464-1:2011

Luminance and luminance distribution

Table 5.13 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Figure 5.13 shows the luminance map used for the calculations.

Average luminance of the horizontal band of width 40º was 34 cd/m^2, which is lower than the values from lively setting's 1 and 2. However, the room could still be perceived as 'bright'. Average luminance on the task area and the self-luminous partition were 115 cd/m^2 and 47cd/m^2, respectively. Lively setting 4 involved the use of saturated colours in the cove lighting and the surface of the partition. However, such effects were not characterised by the luminance measurement. The ratio of the maximum and minimum luminance was calculated as 5.6, as shown in Table 5.13.

Table 5.13 A summary of luminance and luminance distribution at lively setting 4

Average luminance in the field of view	Average luminance, $(L_{av}, cd/m^2)$
Average (whole surface + light sources)	47
Average (side walls + partition), L_{av} $(B40)$	34 (>30*)
Average (side walls + partition + task area)	54
Average luminance on each defined surface	
Wall (left)	22.9
Wall (right)	31.3
Ceiling	20.4
Task area	115
Surrounding task area	112
Partition	47
Luminance distribution	
L_{max}/L_{min}	115/20.4 =5.6 (>13**)

*values over 30 cd/m² could be assumed to change our perception of a room from generally dim to generally bright.
**values above 13 could be assumed to change our perception of a room from generally uninteresting to having a degree of visual interest.

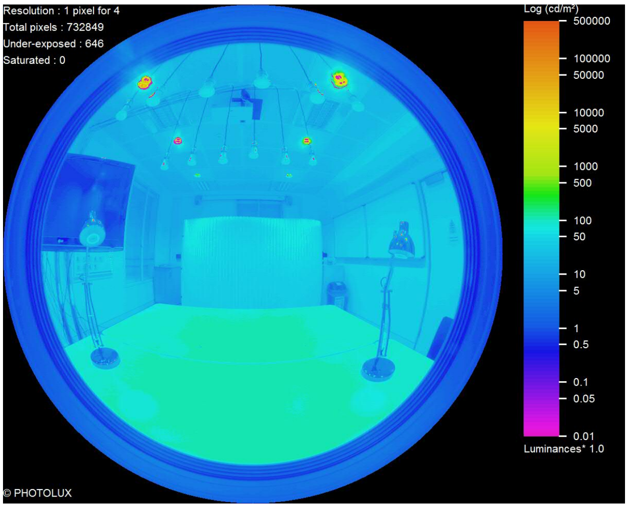


Figure 5.13. The luminance map (lively setting 4)

MRSE and colour aspects

78.1 lm/m² was calculated as the mean room surface exitance (MRSE) within the space. The calculation processes are summarized in Table 5.14. This value is expected to provide lower than an ‘acceptably bright’ appearance although still higher than 30 lm/m², which is defined as a borderline to be perceived as ‘dim’ (Cuttle, 2010). The concept of MRSE does not include colour aspects of lighting appearance and therefore the estimation of room appearance might be found to be different with an extensive use of saturated blue in this setting. The correlated colour temperature at the viewer's eye level was 6,182K and CIE general colour rendering index (R_a) was 87.

Table 5.14 A summary on calculation of MRSE (lively setting 4)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s , lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	20	-	25.2	0.8	1614
Wall (left)	23	-	18	0.7	1294
Wall (right)	31	-	18	0.7	1769
Wall (front)	12	-	12.8	0.7	494
Wall (back)	-	117	12.8	0.5	751
Floor	-	315	22.32	0.2	1406
Task table	115	-	2.88	-	1040
Partition	47	-	5.4	-	797
		Sum	117.4		9165
				MRSE	**78.1**

5.2.5 Lively setting 5

Illuminance and illuminance uniformity

Table 5.15 summarises measured illuminance and calculated illuminance uniformity under lively setting 5. The result indicates that average illuminance on the task area exceeds most of recommendation levels and only marginally lower than 750 lx. Illuminance uniformities on the task area, immediate surrounding area, and background area were all higher than the recommended level. Mean cylindrical illuminance over the space also indicates that the space would be suitable for an activity that requires a great amount of visual communication. Modelling of a person's face sitting next to a viewer (seating position B) would also be acceptable with 0.36 ($E_{cyl}/E_{horizontal}$). Since all of the illuminance related parameters were met by lighting guidance and recommendations, the parameters in relation to luminance were also analysed.

Luminance and luminance distribution

Table 5.16 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Figure 5.14 shows the luminance map used for the calculations. Average luminance of the horizontal band of width 40º was 61 cd/m^2, and if including the task area, the average value increased to 118 cd/m^2. Average luminance on the task area and self-luminous partition were 171 cd/m^2 and 86 cd/m^2, respectively. The average luminance on the task area was approximately four times higher than the average value of the left wall.

Table 5.15 A summary of illuminance and illuminance uniformity at lively setting 5

Horizontal illuminance		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	697(≥500)	0.67(≥0.6)
Immediate surrounding area	540(≥300)	0.52(≥0.4)
Background area	420(33%of task area)	0.30(≥0.1)
Illuminances on surfaces		
Wall (left)	192(≥75)	0.31(≥0.1)
Wall (right)	242(≥75)	0.43 (≥0.1)
Ceiling	173(≥50)	0.22 (≥0.1)
Mean cylindrical illuminance		
	Average illuminance ($E_{cyl},\ lx$)	Uniformity ($E_{min}/E_{max},\ U_o$)
Task + Immediate +background area	225.8(≥ 150)	0.30(≥0.1)
Vertical illuminance		447
Indicator of modelling		
$E_{cyl}/E_{horizontal}$		0.36 (0.3 to 0.6)
$\boldsymbol{E}/E_{sr}$		2.13 (1.2 to 1.8)

Note: values in brackets indicates the recommended level set by European Standard, EN12464-1:2011

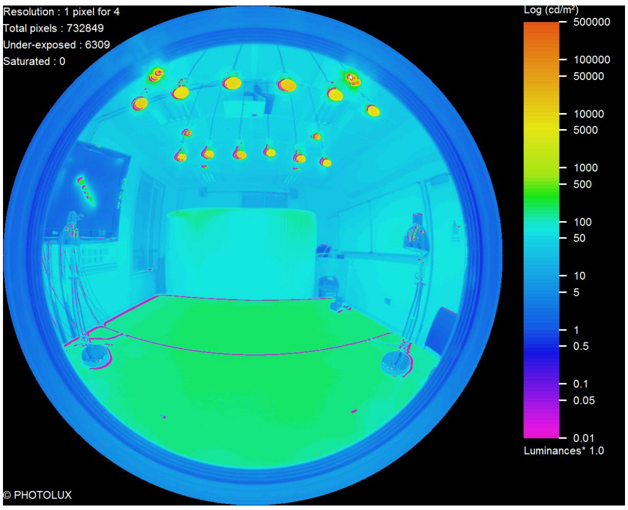


Figure 5.14. The luminance map (lively setting 5)

Table 5.16 A summary of luminance and luminance distribution at lively setting 5

Average luminance in the field of view	Average luminance, ($L_{av}, cd/m^2$)
Average (whole surface + light sources)	156
Average (side walls + partition), L_{av} $(B40)$	61 (>30)
Average (side walls + partition + task area)	118
Average luminance on each defined surface	
Wall (left)	43
Wall (right)	54
Ceiling	55
Task area	171
Surrounding task area	170
Partition	86
Luminance distribution	
L_{max}/L_{min}	171/43 =4 (>13)

MRSE and colour aspects

146.4 lm/m^2 was calculated as the mean room surface exitance (MRSE) within the space under lively setting 5. The calculation processes are summarized in Table 5.17. Since the value exceeds 100 lm/m^2, more than 'acceptably bright' appearance of the room is expected. The correlated colour temperature at a viewer's eye level was 5,815K and the CIE general colour rendering index (R_a) was 84.

Table 5.17 A summary on calculation of MRSE (lively setting 5)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s , lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	55	-	25.2	0.8	4352
Wall (left)	43	-	18	0.7	2430
Wall (right)	54	-	18	0.7	3052
Wall (front)	25	-	12.8	0.7	993
Wall (back)	-	224	12.8	0.5	1433
Floor	-	432	22.32	0.2	1927
Task table	171	-	2.88	-	1546
Partition	86	-	5.4	-	1458
		Sum	117.4		17192
				MRSE	**146.4**

5.3 Characteristics of 'relaxing' settings

5.3.1 Relaxing setting 1

Illuminance and illuminance uniformity

The photometric and colorimetric characteristics of the five relaxing settings were also measured and analysed. First, the illuminance and illuminance uniformity at relaxing setting 1 was measured, as summarised in Table 5.18. The obtained illuminance parameters indicate that an appropriate amount of light falls into the task area, surrounding area and background area for most tasks. Spatial uniformity of horizontal illuminance was also shown to be higher than the recommendation levels. Illumination of wall surfaces and ceiling were also satisfied by meeting the guidelines. Relaxing setting 1 would also be suitable for a space where good visual communication is important. The rendered quality of a person' face sitting next to each other would also be acceptable, particularly at the seating position A (based on the values of modelling index).

Table 5.18 A summary of illuminance and illuminance uniformity at relaxing setting 1

Horizontal illuminance		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	604(≥500)	0.78(≥0.6)
Immediate surrounding area	503(≥300)	0.66(≥0.4)
Background area	422(33%of task area)	0.37(≥0.1)
Illuminances on surfaces		
Wall (left)	209(≥75)	0.25 (≥0.1)
Wall (right)	259(≥75)	0.46 (≥0.1)
Ceiling	138 (≥50)	0.29 (≥0.1)
Mean cylindrical illuminance		
	Average illuminance ($E_{cyl},\ lx$)	Uniformity ($E_{min}/E_{max},\ U_o$)
Task + Immediate +background area	200.6(≥ 150)	0.45(≥0.1)
Vertical illuminance		325
Indicator of modelling		
$E_{cyl}/E_{horizontal}$		0.37 (0.3 to 0.6)
$\boldsymbol{E}/E_{sr}$		2.19 (1.2 to 1.8)

Note: values in brackets indicates the recommended level set by European Standard, EN12464-1:2011

Luminance and luminance distribution

Luminance and luminance distribution were also obtained from relaxing setting 1. Table 5.19 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Figure 5.15 shows the luminance map used for the calculations. Average luminance of the horizontal band of width 40º was 61 cd/m^2, and if including task area, the average value increased to 76.5 cd/m^2. Average luminance on the task area and the self-luminous partition was 131 cd/m^2 and 88 cd/m^2, respectively. The ratio of the maximum luminance and minimum luminance was approximately 3.6.

Table 5.19 A summary of luminance and luminance distribution at relaxing setting 1

Average luminance in the field of view	Average luminance, ($L_{av}, cd/m^2$)
Average (whole surface + light sources)	74
Average (side walls + partition), L_{av} $(B40)$	61 (>30)
Average (side walls + partition + task area)	76.5
Average luminance on each defined surface	
Wall (left)	40
Wall (right)	47
Ceiling	36
Task area	131
Surrounding task area	124
Partition	88
Luminance distribution	
L_{max}/L_{min}	131/36 =3.6 (>13)

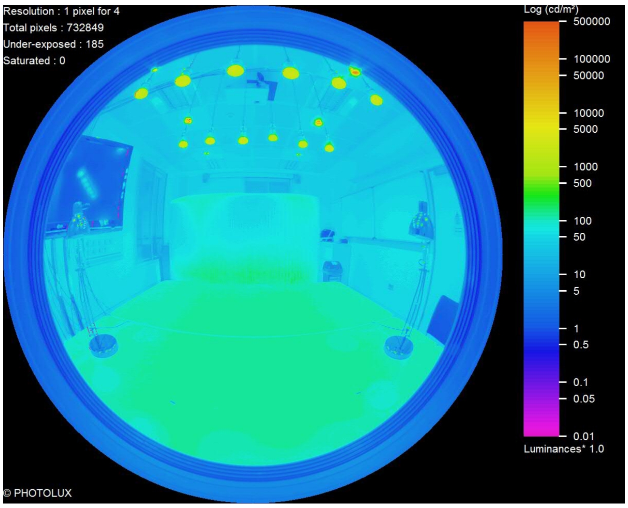


Figure 5.15. The luminance map (relaxing setting 1)

MRSE and colour aspects

129.2 lm/m^2 was calculated as the mean room surface exitance (MRSE) within the space under relaxing setting 1. The calculation processes were summarised in Table 5.20. Since the value exceeds 100 lm/m^2, more than an 'acceptably bright' appearance of the room is expected. The correlated colour temperature at a viewer's eye level was 2,896K and CIE general colour rendering index (R_a) was 87. An overall warm colour appearance with good colour rendering quality is expected from these results.

Table 5.20 A summary on calculation of MRSE (relaxing setting 1)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s , lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	36	-	25.2	-	2849
Wall (left)	40	-	18	-	2261
Wall (right)	47	-	18	-	2656
Wall (front)	28	-	12.8	-	1005
Wall (back)	-	198	12.8	0.5	1270
Floor	-	552	22.32	0.2	2460
Task table	131	-	2.88	-	1185
Partition	88	-	5.4	-	1492
		Sum	117.4		15177
				MRSE	**129.2**

5.3.2 Relaxing setting 2

Illuminance and illuminance uniformity

Obtained illuminance and illuminance uniformity at relaxing setting 2 is summarised in Table 5.21. The average illuminance on the task area (333 lux) indicates that the space would be acceptable for filing and copying types of work according to the European Standard, EN 12464-1:2011. Spatial uniformity of horizontal illuminance was shown to be higher than the recommendation levels. Illumination of wall surfaces and ceiling were also satisfied by meeting the guidelines. Mean cylindrical illuminance and its uniformity within the space suggests that relaxing setting 2 would also be suitable for a space where good visual communication is important. The rendered quality of persons sitting next to each other would also be acceptable (0.45).

Table 5.21 A summary of illuminance and illuminance uniformity at relaxing setting 2

Horizontal illuminance		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	333(≥300)	0.66(≥0.6)
Immediate surrounding area	268(≥300)	0.48(≥0.4)
Background area	245(33%of task area)	0.34(≥0.1)
Illuminances on surfaces		
Wall (left)	133(≥75)	0.35 (≥0.1)
Wall (right)	163 (≥75)	0.35 (≥0.1)
Ceiling	122 (≥50)	0.29 (≥0.1)
Mean cylindrical illuminance		
	Average illuminance ($E_{cyl},\ lx$)	Uniformity ($E_{min}/E_{max},\ U_o$)
Task + Immediate +background area	155.8($\geq$ 150)	0.37(≥0.1)
Vertical illuminance		228
Indicator of modelling		
$E_{cyl}/E_{horizontal}$		0.45 (0.3 to 0.6)
$\boldsymbol{E}/E_{sr}$		1.63 (1.2 to 1.8)

Note: values in brackets indicates the recommended level set by European Standard, EN12464-1:2011

Luminance and luminance distribution

Luminance and luminance distribution were also obtained for relaxing setting 2. Table 5.22 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Figure 5.16 shows the luminance map used for the calculations. Average luminance of the horizontal band of width 40º was 61 cd/m^2, and if including the task area, the average value increased to 66 cd/m^2. Average luminance on the task area and the self-luminous partition were 74 cd/m^2 and 120 cd/m^2, respectively. The ratio between highest luminance and lowest luminance on surface was approximately 3.9.

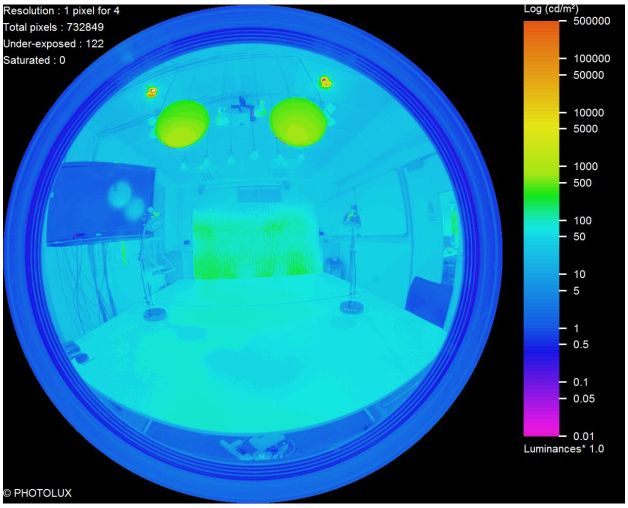


Figure 5.16. The luminance map (relaxing setting 2)

Table 5.22 A summary of luminance and luminance distribution at relaxing setting 2

Average luminance in the field of view	Average luminance, $(L_{av}, cd/m^2)$
Average (whole surface + light sources)	68
Average (side walls + partition), L_{av} $(B40)$	63 (>30)
Average (side walls + partition + task area)	66
Average luminance on each defined surface	
Wall (left)	36
Wall (right)	34
Ceiling	31
Task area	74
Surrounding task area	67
Partition	120
Luminance distribution	
L_{max}/L_{min}	120/31 =3.9 (>13)

MRSE and colour aspects

106.2 lm/m^2 was calculated as the mean room surface exitance (MRSE) within the space under relaxing setting 1. The calculation processes are summarized in Table 5.23. Since the value just meets 100 lm/m^2, perception of a minimum level of 'acceptably bright' appearance of the room was expected. The correlated colour temperature at a viewer's eye level was 2,901K and CIE general colour rendering index (R_a) was 96. An overall warm colour appearance with good colour rendering quality is expected from these results.

Table 5.23 A summary on calculation of MRSE (relaxing setting 2)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s , lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	31	-	25.2	-	2453
Wall (left)	34	-	18	-	2035
Wall (right)	36	-	18	-	1922
Wall (front)	31	-	12.8	-	1246
Wall (back)	-	146	12.8	0.5	932
Floor	-	264	22.32	0.2	1177
Task table	74	-	2.88	-	669
Partition	120	-	5.4	-	2035
		Sum	117.4		12468
				MRSE	**106.2**

5.3.3 Relaxing setting 3

Illuminance and illuminance uniformity

Obtained illuminances and illuminance uniformity at relaxing setting 3 is summarised in Table 5.24. The average illuminance on the task area indicates that the space would be acceptable for filing and copying types of work. Spatial uniformity of horizontal illuminance was shown to be higher than the recommendation levels. However, the average illuminance on the surrounding area and the back area were lower than the recommendation set by the European Standard. Illumination of wall surfaces and ceiling achieved the minimum values of the guidelines. Mean cylindrical illuminance and its uniformity within the space suggests that relaxing setting 2 would not be suitable for a space where good visual communication is important. The calculated modelling index values ($E_{cyl}/E_{horizontal}$=1.15 for seating position A and $E_{cyl}/E_{horizontal}$=0.62 for seating position B) were outside of the recommendation range.

Luminance and luminance distribution

Luminance and luminance distribution were also obtained from relaxing setting 3. Table 5.25 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Figure 5.17 shows the luminance map used for the calculations. Average luminance of the horizontal band of width 40º was 14 cd/m^2, and if including the task area, the average value increased to 32 cd/m^2. Average luminance on the task area and the self-luminous partition were 85 cd/m^2 and 16 cd/m^2, respectively. The ratio between the maximum luminance and minimum luminance on surface was approximately 8.5.

Table 5.24 A summary of illuminance and illuminance uniformity at relaxing setting 3

Horizontal illuminance		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	312(≥300)	0.46(≥0.6)
Immediate surrounding area	93(≥200)	0.38(≥0.4)
Background area	61(33%of task area)	0.31(≥0.1)
Illuminances on surfaces		
Wall (left)	53 (≥75)	0.36 (≥0.1)
Wall (right)	53 (≥75)	0.16 (≥0.1)
Ceiling	58 (≥50)	0.13 (≥0.1)
Mean cylindrical illuminance		
	Average illuminance ($E_{cyl},\ lx$)	Uniformity ($E_{min}/E_{max},\ U_o$)
Task + Immediate +background area	63.8(≥ 150)	0.19(≥0.1)
Vertical illuminance		150
Indicator of modelling		
$E_{cyl}/E_{horizontal}$		0.62 (0.3 to 0.6)
$\boldsymbol{E}/E_{sr}$		1.69 (1.2 to 1.8)

Note: values in brackets indicates the recommended level set by European Standard, EN12464-1:2011

Table 5.25 A summary of luminance and luminance distribution at relaxing setting 3

Average luminance in the field of view	Average luminance, ($L_{av}, cd/m^2$)
Average (whole surface + light sources)	36
Average (side walls + partition), L_{av} $(B40)$	14 (>30*)
Average (side walls + partition + task area)	32
Average luminance on each defined surface	
Wall (left)	10
Wall (right)	16
Ceiling	23
Task area	167
Surrounding task area	85
Partition	16
Luminance distribution	
L_{max}/L_{min}	167/10 =16.7 (>13**)

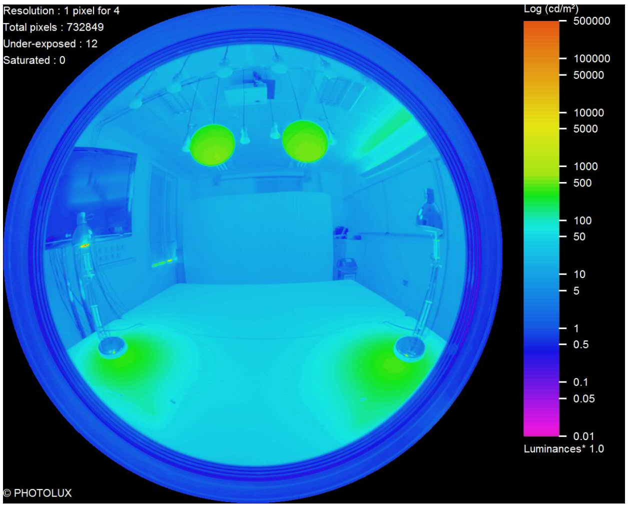


Figure 5.17. The luminance map (relaxing setting 3)

MRSE and colour aspects

46.7 lm/m^2 was calculated as the mean room surface exitance (MRSE) within the space under relaxing setting 3. The calculation processes are summarised in Table 5.26. Since the value is much lower than 100 lm/m^2, the appearance of the room is expected to be lower than acceptably bright (still higher than 30 lm/m^2, which indicates a 'dim' appearance). The correlated colour temperature at a viewer's eye level was 2,656K and CIE general colour rendering index (R_a) was 95. An overall warm colour appearance with good colour rendering quality is expected from the values.

Table 5.26 A summary on calculation of MRSE (relaxing setting 3)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s , lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	23	-	25.2	-	1788
Wall (left)	10	-	18	-	565
Wall (right)	16	-	18	-	904
Wall (front)	10	-	12.8	-	378
Wall (back)	-	78	12.8	0.5	498
Floor	-	71	22.32	0.2	316
Task table	85	-	2.88	-	769
Partition	16	-	5.4	-	263
		Sum	117.4		5480
				MRSE	**46.7**

5.3.4 Relaxing setting 4

Illuminance and illuminance uniformity

Obtained illuminance and illuminance uniformity at relaxing setting 4 is summarised in Table 5.27. The average illuminance on the task area indicates that the space would be acceptable for filing and copying types of work and probably suitable for reading and writing according to the European Standard, EN12464-1:2001. Spatial non-uniformity of each surface was shown to be higher than the recommendation levels. The average illuminance on the surrounding area and the background area achieved the recommendation set by the European Standard. Illumination of wall surfaces and ceiling achieved the minimum values of the guidelines. Mean cylindrical illuminance and its uniformity within the space suggests that relaxing setting 2 would be close to suitable for a space where good visual communication is important. The modelling index (0.66) was slightly outside of the recommendation range.

Table 5.27 A summary of illuminance and illuminance uniformity at relaxing setting 4

Horizontal illuminance		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	389(≥300)	0.55(≥0.6)
Immediate surrounding area	231(≥200)	0.32(≥0.4)
Background area	119(33%of task area)	0.26(≥0.1)
Illuminances on surfaces		
Wall (left)	93 (≥75)	0.32 (≥0.1)
Wall (right)	133 (≥75)	0.33 (≥0.1)
Ceiling	133 (≥50)	0.15 (≥0.1)
Mean cylindrical illuminance		
	Average illuminance ($E_{cyl},\ lx$)	Uniformity ($E_{min}/E_{max},\ U_o$)
Task + Immediate +background area	136 (≥ 150)	0.12 (≥0.1)
Vertical illuminance		315
Indicator of modelling		
$E_{cyl}/E_{horizontal}$		0.66 (0.3 to 0.6)
$\boldsymbol{E}/E_{sr}$		2.19 (1.2 to 1.8)

Note: values in brackets indicates the recommended level set by European Standard, EN12464-1:2011

Luminance and luminance distribution

Luminance and luminance distribution were also obtained from relaxing setting 4. Table 5.28 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Figure 5.18 shows the luminance map used for the calculations. The average luminance of the horizontal band of width 40º was 29 cd/m^2, and if including the task area, the average value increased to 43 cd/m^2. Average luminance on the task area and self-luminous partition were 98 cd/m^2 and 43 cd/m^2, respectively. The ratio between the maximum luminance and the minimum luminance on surface was approximately 6.1.

Table 5.28 A summary of luminance and luminance distribution at relaxing setting 4

Average luminance in the field of view	Average luminance, $(L_{av}, cd/m^2)$
Average (whole surface + light sources)	152
Average (side walls + partition), L_{av} $(B40)$	29 (>30*)
Average (side walls + partition + task area)	43
Average luminance on each defined surface	
Wall (left)	16
Wall (right)	25.4
Ceiling	31
Task area	98
Surrounding task area	98
Partition	43
Luminance distribution	
L_{max}/L_{min}	98/16 =3.9 (>13**)

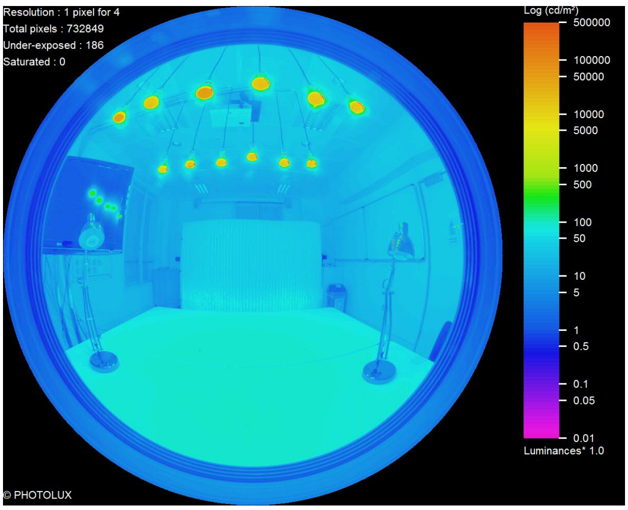


Figure 5.18. The luminance map (relaxing setting 4)

MRSE and colour aspects

71.6 lm/m^2 was calculated as the mean room surface exitance (MRSE) within the space under relaxing setting 4. The calculation processes are summarized in Table 5.29. Since the value is lower than 100 lm/m^2, appearance of the room is expected to be lower than acceptably bright. The correlated colour temperature at the viewer's eye level was 3,069K and CIE general colour rendering index (R_a) was 92. An overall warm colour appearance with good colour rendering quality is expected from the values.

Table 5.29 A summary on calculation of MRSE (relaxing setting 4)

	Average luminance $L_s, cd/m^2$	Average illuminance $E_s\ , lx$	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	31	-	25.2	-	2453
Wall (left)	16	-	18	-	904
Wall (right)	25	-	18	-	1436
Wall (front)	14	-	12.8	-	563
Wall (back)	-	128	12.8	0.5	817
Floor	-	138	22.32	0.2	616
Task table	98	-	2.88	-	886
Partition	43	-	5.4	-	729
		Sum	117.4		8404
				MRSE	**71.6**

5.3.5 Relaxing setting 5

Illuminance and illuminance uniformity

Obtained illuminance and illuminance uniformity at relaxing setting 5 is summarised in Table 5.30. Since this setting suggests using only table lamps for the task lighting, the illuminance parameters were all outside of the recommendation levels for a general office. Average illuminance on the task area was close to 300 lx. Although the values seem to be low in number, users, in reality, can adjust the location of the table lights and therefore the amount of light falling on the task area would not be too low.

Obviously, this setting is suitable for a space where visual communication is important, but also provides a poor modelling quality.

Table 5.30 A summary of illuminance and illuminance uniformity at relaxing setting 5

Horizontal illuminance		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	285(≥300)	0.05(≥0.6)
Immediate surrounding area	30 (≥200)	0.31(≥0.4)
Background area	27(33%of task area)	0.15 (≥0.1)
Illuminances on surfaces		
Wall (left)	24 (≥75)	0.28 (≥0.1)
Wall (right)	25 (≥75)	0.44 (≥0.1)
Ceiling	35 (≥50)	0.37 (≥0.1)
Mean cylindrical illuminance		
	Average illuminance ($E_{cyl},\ lx$)	Uniformity ($E_{min}/E_{max},\ U_o$)
Task + Immediate +background area	27.4 (≥ 150)	0.54 (≥0.1)
Vertical illuminance		110
Indicator of modelling		
$E_{cyl}/E_{horizontal}$		1.56 (0.3 to 0.6)
$\boldsymbol{E}/E_{sr}$		1.74 (1.2 to 1.8)

Note: values in brackets indicates the recommended level set by European Standard, EN12464-1:2011

Luminance and luminance distribution

Luminance and luminance distribution were also obtained from relaxing setting 5. Table 5.31 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Figure 5.19 shows the luminance map used for the calculations. Average luminance of the horizontal band of width 40º was 15.1 cd/m^2, and if including the task area, the average value increased to 25 cd/m^2. Average luminance on the task area and the self-luminous partition were 65 cd/m^2 and 39 cd/m^2, respectively. The ratio between the maximum luminance and the minimum luminance on the surfaces was approximately 10.

Table 5.31 A summary of luminance and luminance distribution at relaxing setting 5

Average luminance in the field of view	Average luminance, $(L_{av}, cd/m^2)$
Average (whole surface + light sources)	24.2
Average (side walls + partition), $L_{av}\ (B40)$	15.1 (>30*)
Average (side walls + partition + task area)	25
Average luminance on each defined surface	
Wall (left)	6.5
Wall (right)	7.4
Ceiling	7.5
Task area	167
Surrounding task area	25
Partition	39
Luminance distribution	
L_{max}/L_{min}	167/6.5 =25.7 (>13**)

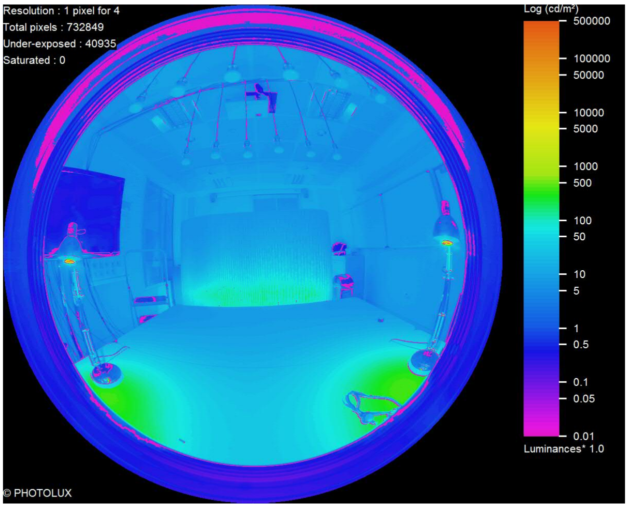


Figure 5.19. The luminance map (relaxing setting 5)

<u>MRSE and colour aspects</u>

28.6 lm/m^2 was calculated as the mean room surface exitance (MRSE) within the space under relaxing setting 5. The calculation processes are summarized in Table 5.32. The calculated MRSE value was the lowest among the ten designers' inspired settings. Since the value is below 30, the space is expected to be perceived as 'dim' in appearance. The correlated colour temperature at a viewer's eye level was 2,659 K and the CIE general colour rendering index (R_a) was 93. An overall warm colour appearance with good colour rendering quality is expected from the values.

Table 5.32 A summary on calculation of MRSE (relaxing setting 5)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s , lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	7.5	-	25.2	-	593
Wall (left)	6.5	-	18	-	367
Wall (right)	7.4	-	18	-	418
Wall (front)	9.6	-	12.8	-	386
Wall (back)	-	33	12.8	0.5	214
Floor	-	30	22.32	0.2	132
Task table	65	-	2.88	-	588
Partition	39	-	5.4	-	661
		Sum	117.4		3360
				MRSE	**28.6**

5.4 Characteristics of 'miscellaneous' settings

Photometric and colorimetric characteristics of the five miscellaneous settings were also measured and analysed. Since these settings were intentionally made by the author to test impacts of lighting on human perception of space and emotion, some illuminance parameters for office lighting such as the illuminance on walls, ceiling and mean cylindrical illuminance were not considered.

5.4.1 Miscellaneous setting 1

Illuminance and illuminance uniformity

The intention of miscellaneous setting 1 was well characterised by illuminance parameters, as shown in Table 5.33. Average illuminance on the task area exceeds 1,800 lx, which is by far the highest level compared to values from the other settings. Vertical illuminance at viewer's eye level also exceeds 1,000 lx. Miscellaneous setting 1 was intended to create the brightest appearance and expected to create a high level of activation.

Luminance and luminance distribution

Luminance and luminance distribution were also obtained from miscellaneous setting 1. Table 5.34 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Figure 5.20 shows the luminance map used for the calculations.

Average luminance of the horizontal band of width 40º was 118 cd/m^2, and if including the task area, the average value increased to 193.5 cd/m^2. Average luminance on the task area and self-luminous partition were 420 cd/m^2 and 177 cd/m^2, respectively. The ratio between the maximum luminance and minimum luminance on surface was approximately 5.6.

Table 5.33 A summary of illuminance and illuminance uniformity at miscellaneous setting 1

Horizontal illuminance (at working plane height: 0.8m)		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	1873	0.50
Immediate surrounding area	1108	0.51
Background area	829	0.29
Vertical illuminance		1053
Indicator of modelling		
$E_{cyl}/E_{horizontal}$		0.42
$\boldsymbol{E}/E_{sr}$		1.90

Table 5.34 A summary of luminance and luminance distribution at miscellaneous setting 1

Average luminance in the field of view	
Average (whole surface + light sources)	380
Average (side walls + partition), L_{av} $(B40)$	118
Average (side walls + partition + task area)	193.5
Average luminance on each defined surface	Average luminance, ($L_{av}, cd/m^2$)
Wall (left)	75
Wall (right)	102
Ceiling	92
Task area	580
Surrounding task area	420
Partition	177
Luminance distribution	
L_{max}/L_{min}	580/75 =7.7

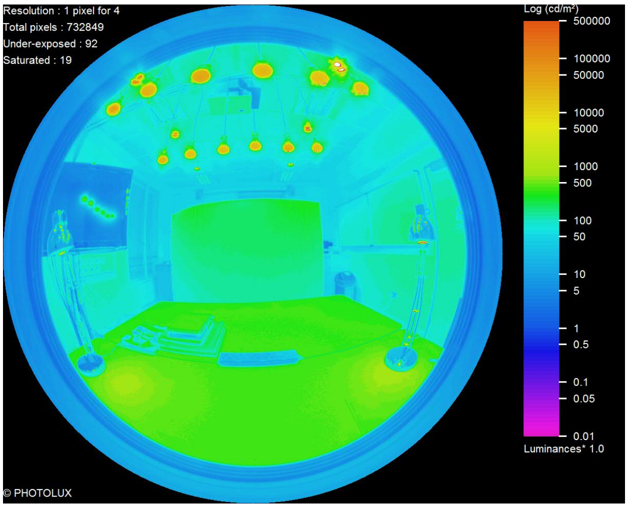


Figure 5.20. The luminance map (miscellaneous setting 1)

MRSE and colour aspects

273 lm/m^2 was calculated as the mean room surface exitance (MRSE) within the space under miscellaneous setting 1. The calculation processes are summarized in Table 5.35. Importantly, the real value of MRSE would be higher than the one obtained here as the calculations did not include the all the surfaces. Cuttle (2010) suggests that an MRSE=300lm/m^2 could described be as a 'bright' appearance, and it makes sense that this setting also achieve the same perception. The correlated colour temperature at a viewer's eye level was 6,669 K and the CIE general colour rendering index (R_a) was 86.

Table 5.35 A summary on calculation of MRSE (miscellaneous setting 1)

	Average luminance $L_s, cd/m^2$	Average illuminance $E_s\ , lx$	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	92	-	25.2	-	7280
Wall (left)	75	-	18	-	4239
Wall (right)	102	-	18	-	5765
Wall (front)	44	-	12.8	-	1768
Wall (back)	-	380	12.8	0.5	2432
Floor	-	832	22.32	0.2	3714
Task table	420	-	2.88	-	3798
Partition	177	-	5.4	-	3001
		Sum	117.4		31998
				MRSE	**273**

5.4.2 Miscellaneous setting 2

Illuminance and illuminance uniformity

Table 5.36 summarises the obtained illuminance and illuminance uniformity values under miscellaneous setting 2. Average illuminance on the task area was 1,312 lx, which is the second highest level compared to values from the other settings. All of the other illuminance parameters indicate a similar luminous environment to miscellaneous setting 1 but slightly lower in general.

Luminance and luminance distribution

Luminance and luminance distribution were also obtained from miscellaneous setting 2. Table 5.37 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Figure 5.21 shows the luminance map used for the calculations. Average luminance of the horizontal band of width 40º was 81 cd/m^2, and if including the task area, the average value increased to 138.5 cd/m^2. Average luminance on the task area and the self-luminous partition were 311 cd/m^2 and 120 cd/m^2, respectively. The ratio between the maximum luminance and minimum luminance was approximately 6.1. Again, all of the luminance parameters were by far the second highest among the other settings.

Table 5.36 A summary of illuminance and illuminance uniformity at miscellaneous setting 2

Horizontal illuminance (at working plane height: 0.8m)		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	1312	0.58
Immediate surrounding area	830	0.55
Background area	640	0.38
Vertical illuminance		753
Indicator of modelling		Seating position B
$E_{cyl}/E_{horizontal}$		0.42
$\boldsymbol{E}/E_{sr}$		1.79

Table 5.37 A summary of luminance and luminance distribution at miscellaneous setting 2

Average luminance in the field of view	Average luminance, $(L_{av}, cd/m^2)$
Average (whole surface + light sources)	320
Average (side walls + partition), L_{av} $(B40)$	81
Average (side walls + partition + task area)	138.5
Average luminance on each defined surface	
Wall (left)	51
Wall (right)	71
Ceiling	63
Task area	440
Surrounding task area	311
Partition	120
Luminance distribution	
L_{max}/L_{min}	440/51 =8.6

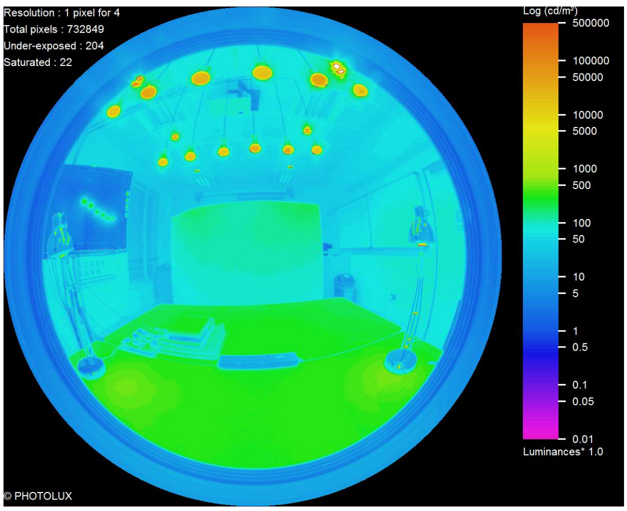


Figure 5.21. The luminance map (miscellaneous setting 2)

<u>MRSE and colour aspects</u>

196 lm/m^2 was calculated as the mean room surface exitance (MRSE) within the space under miscellaneous setting 2. The calculation processes are summarised in Table 5.38. The obtained MRSE was second highest among the other settings. The correlated colour temperature at the viewer's eye level was 2,274 K and CIE general colour rendering index (R_a) was 83.

Table 5.38 A summary on calculation of MRSE (miscellaneous setting 2)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s , lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	63	-	25.2	-	4985
Wall (left)	51	-	18	-	2882
Wall (right)	71	-	18	-	4012
Wall (front)	33	-	12.8	-	1336
Wall (back)	-	320	12.8	0.5	2048
Floor	-	642	22.32	0.2	2866
Task table	311	-	2.88	-	2812
Partition	120	-	5.4	-	2034
		Sum	117.4		22969
				MRSE	**196**

5.4.3 Miscellaneous setting 3

Illuminance and illuminance uniformity

Table 5.39 summarises the obtained illuminance and illuminance uniformity values under miscellaneous setting 3. Average illuminance on the task area was 388 lx. Since this setting involves only table lamps for task lighting, a high level of non-uniformity in the spatial distribution was found. The obtained modelling index values were also outside the range of recommended levels.

Luminance and luminance distribution

Luminance and luminance distribution were also obtained from miscellaneous setting 3. Table 5.40 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Figure 5.22 shows the luminance map used for the calculations. Average luminance of the horizontal band of width 40º was 59 cd/m^2, and if including the task area, the average value increased to 71 cd/m^2. Average luminance on the task area and the self-luminous partition were 106 cd/m^2 and 122 cd/m^2, respectively. The ratio between the maximum luminance and the minimum luminance on surface was approximately 8.1.

Table 5.39 A summary of illuminance and illuminance uniformity at miscellaneous setting 3

Horizontal illuminance (at working plane height: 0.8m)		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	388	0.11
Immediate surrounding area	95	0.47
Background area	109	0.12
Vertical illuminance		198
Indicator of modelling	Seating position A	Seating position B
$E_{cyl}/E_{horizontal}$	1.45	0.81
$\boldsymbol{E}/E_{sr}$	1.71	1.23

Table 5.40 A summary of luminance and luminance distribution at miscellaneous setting 3

Average luminance in the field of view	Average luminance, ($L_{av}, cd/m^2$)
Average (whole surface + light sources)	45
Average (side walls + partition), L_{av} $(B40)$	59
Average (side walls + partition + task area)	71
Average luminance on each defined surface	
Wall (left)	15
Wall (right)	39
Ceiling	25
Task area	106
Surrounding task area	183
Partition	122
Luminance distribution	
L_{max}/L_{min}	183/15 =12

MRSE and colour aspects

80.2 lm/m^2 was calculated as the mean room surface exitance (MRSE) within the space under miscellaneous setting 3. The calculation processes are summarized in Table 5.41. The correlated colour temperature at the viewer's eye level was 5,928 K and the CIE general colour rendering index (R_a) was 79.

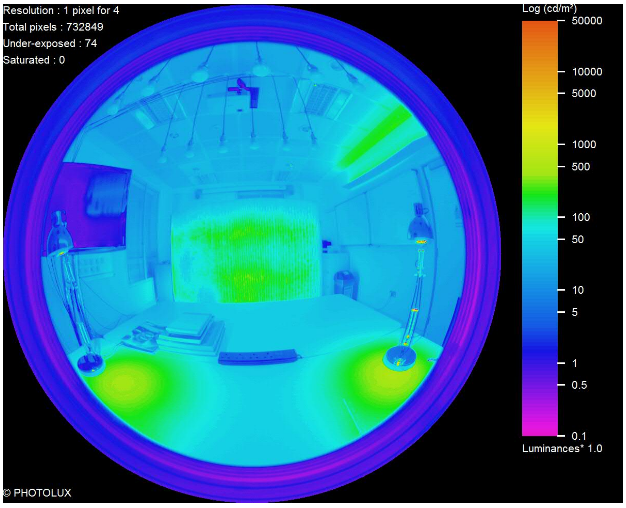


Figure 5.22. The luminance map (miscellaneous setting 3)

Table 5.41 A summary on calculation of MRSE (miscellaneous setting 3)

	Average luminance $L_s, cd/m^2$	Average illuminance $E_s\ , lx$	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	25	-	25.2	-	1978
Wall (left)	15	-	18	-	848
Wall (right)	39	-	18	-	2204
Wall (front)	26	-	12.8	-	1044
Wall (back)	-	40	12.8	0.5	256
Floor	-	108	22.32	0.2	483
Task table	106	-	2.88	-	959
Partition	122	-	5.4	-	2068
		Sum	117.4		9840
				MRSE	**83.8**

5.4.4 Miscellaneous setting 4

Illuminance and illuminance uniformity

Table 5.42 summarises the obtained illuminance and illuminance uniformity values under miscellaneous setting 4. Average illuminance on the task area was 220 lx, which is by far the lowest level compared to values from the other settings. All of the other illuminance parameters indicate a similar luminous environment to miscellaneous setting 3 but slightly lower in general. As intended, this setting achieved the lowest values in the illuminance parameter.

Luminance and luminance distribution

Luminance and luminance distribution were also obtained from miscellaneous setting 4. Table 5.43 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Figure 5.23 shows the luminance map used for the calculations. Average luminance of the horizontal band of width 40º was 18 cd/m^2, and if including the task area, the average value increased to 27 cd/m^2.

Table 5.42 A summary of illuminance and illuminance uniformity at miscellaneous setting 4

Horizontal illuminance (at working plane height: 0.8m)		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	220	0.05
Immediate surrounding area	38	0.45
Background area	38	0.25
Vertical illuminance		103
Indicator of modelling		Seating position B
$E_{cyl}/E_{horizontal}$		0.96
$\boldsymbol{E}/E_{sr}$		0.82

Table 5.43 A summary of luminance and luminance distribution at miscellaneous setting 4

Average luminance on light source(s)	
	Average luminance, ($L_{av}, cd/m^2$)
Light source (Table lamps)	650
Average luminance in the field of view	
Average (whole surface + light sources)	22
Average (side walls + partition), L_{av} $(B40)$	18
Average (side walls + partition + task area)	27
Average luminance on each defined surface	
Wall (left)	10
Wall (right)	10
Ceiling	12
Task area	97
Surrounding task area	64
Partition	39
Luminance distribution	
L_{max}/L_{min}	97/10 =9.7

<u>MRSE and colour aspects</u>

34.7 lm/m^2 was calculated as the mean room surface exitance (MRSE) within the space under miscellaneous setting 4. Such a value was the second lowest among the fifteen settings followed by relaxing setting 5. The calculation processes are shown in Table 5.44. The correlated colour temperature at the viewer's eye level was 1,950 K and CIE general colour rendering index (R_a) was 76.

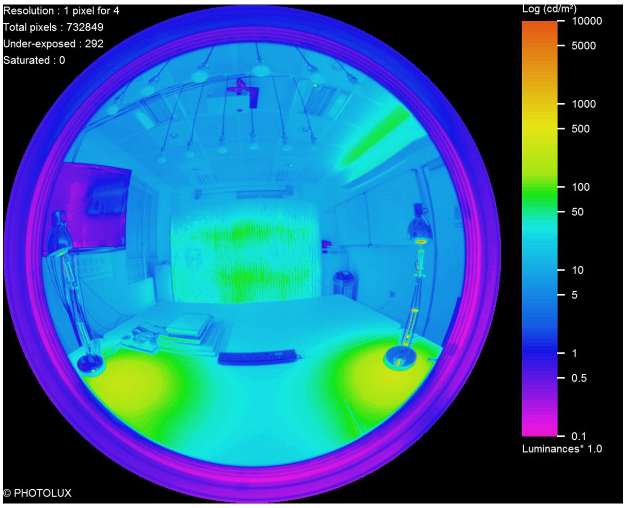


Figure 5.23. The luminance map (miscellaneous setting 4)

Table 5.44 A summary on calculation of MRSE (miscellaneous setting 4)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s , lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	12	-	25.2	-	950
Wall (left)	10	-	18	-	565
Wall (right)	10	-	18	-	565
Wall (front)	10	-	12.8	-	394
Wall (back)	-	30	12.8	0.5	192
Floor	-	38	22.32	0.2	170
Task table	64	-	2.88	-	579
Partition	39	-	5.4	-	661
		Sum	117.4		4076
				MRSE	**34.7**

5.4.5 Miscellaneous setting 5

Illuminance and illuminance uniformity

Table 5.45 summarises the obtained illuminance and illuminance uniformity values under miscellaneous setting 5. As stated earlier, this setting intentionally includes the highest level of colour contrast in its appearance. Therefore, regardless of the illuminance values, the environment would not be suitable for a workspace.

Luminance and luminance distribution

Luminance and luminance distribution were also obtained from miscellaneous setting 5. Table 5.46 summarises the average luminance on each surface as well as the calculated luminance distribution in the field of view. Although the luminance map was produced by PHOTOLUX 3.2, the value seems fairly unreliable. This is probably due to the fact that the colours and intensities all the lights were continuously changing while measurement took place.

MRSE and colour aspects

57.1 lm/m^2 was calculated as the mean room surface exitance (MRSE) within the space under miscellaneous setting 5. The calculation processes are shown in Table 5.47. Due to continuous colour changes from pre-programmed light sources, the colour aspects under miscellaneous setting 5 were not measured.

Table 5.45 A summary of illuminance and illuminance uniformity at miscellaneous setting 5

Horizontal illuminance (at working plane height: 0.8m)		
	Average illuminance (E, lx)	Uniformity ($E_{min}/E_{max}, U_o$)
Task area	329	0.40
Immediate surrounding area	187	0.30
Background area	115	0.25
Vertical illuminance		285
Indicator of modelling		
$E_{cyl}/E_{horizontal}$		0.62
$\boldsymbol{E}/E_{sr}$		1.92

Table 5.46 A summary of luminance and luminance distribution at miscellaneous setting 5

Average luminance on light source(s)	
	Average luminance, ($L_{av}, cd/m^2$)
Average luminance in the field of view	
Average (whole surface + light sources)	36
Average (side walls + partition), L_{av} $(B40)$	26
Average (side walls + partition + task area)	35
Average luminance on each defined surface	
Wall (left)	14
Wall (right)	20
Ceiling	24
Task area	72
Surrounding task area	67
Partition	47
Luminance distribution	
L_{max}/L_{min}	72/14 =5.1

Table 5.47 A summary on calculation of MRSE (miscellaneous setting 5)

	Average luminance $L_s, cd/m^2$	Average illuminance E_s , lx	Area of surface A_s, m^2	Reflectance of surface P_s	Exitance from surface $M_s, lm/m^2$
Ceiling	24	-	25.2	-	1899
Wall (left)	14	-	18	-	791
Wall (right)	20	-	18	-	1130
Wall (front)	12	-	12.8	-	474
Wall (back)	-	67	12.8	0.5	448
Floor	-	115	22.32	0.2	512
Task table	72	-	2.88	-	651
Partition	47	-	5.4	-	796
		Sum	117.4		6703
				MRSE	**57.1**

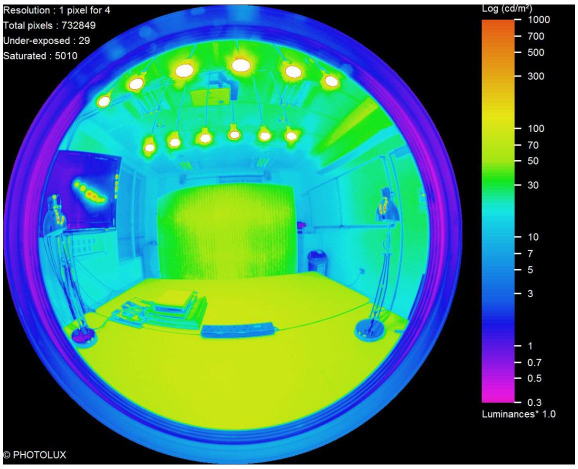


Figure 5.24. The luminance map (miscellaneous setting 5)

5.5 Summary of the chapter: end of Phase I

This chapter has discussed the photometric and the colorimetric characteristics of the fifteen light settings, ten out of which were generated from the participating designers' concepts. A number of illumination parameters were selected to describe their luminous environments based on both SLL Code for lighting and European Standard recommendations in a workspace. Before moving onto the second phase of the field study, a comprehensive summary of the fifteen light settings is provided in this section. For convenience, lively, relaxing and miscellaneous settings have been abbreviated to 'L,' 'R', and 'M'. Therefore, 'L1' in this section indicates 'Lively setting 1'.

First, the use of lighting fixtures in each of the fifteen light settings is summarised. As shown in Table 5.48, eleven out of fifteen settings used pendant lights either with Philips Hue A19 lamps or GU10 lamps.

Table 5.48. A summary of lighting fixture usage for fifteen settings

	Pendant lighting system			Ceiling lights	Self-luminous partition		Wall lighting	Table lamps
	A19[1]	GU10[2]	LS[3]	CL[4]	U[5]	D[6]		
L1	✓			✓		✓		
L2	✓		✓		✓			
L3		✓					✓	
L4				✓	✓		✓	
L5	✓			✓		✓		
R1	✓			✓		✓		
R2	✓		✓	✓	✓			
R3	✓		✓				✓	✓
R4	✓					✓		
R5						✓		✓
M1	✓			✓				✓
M2	✓			✓				✓
M3					✓		✓	✓
M4					✓		✓	✓
M5	✓				✓		✓	

[1]A19 Philips Hue A19 lamps on the pendant lighting
[2]GU10 Philips Hue GU10 lamps on the pendant lighting
[3]LS Globe-shaped lamp shades on the pendant lighting
[4]CL Ceiling luminaires
[5]U Self-luminous partition (uniformly lit)
[6]D Self-luminous partition (directional lighting pattern)

Also, a frequent use of the curved partition as a self-luminous source was observed (eleven out of fifteen settings). The study has concluded that no specific design pattern is associated with either 'lively' or 'relaxing' design settings. Then, photometric and colorimetric characteristics of each light setting was analysed. Table 5.49 shows the summary of key obtained photometric and colorimetric characteristics under fifteen light settings. In terms of colour aspect, it was noticed that the designers approached differently to create 'lively' and 'relaxing' workspace environments.

Table 5.49. A summary of key photometric and colorimetric characteristics of fifteen settings

	E_{task} (U_o)	E_{cyl} (U_o)	$\frac{E_{cyl}}{E_{hor}}$	$\boldsymbol{E}/E_{sr}$	MRSE	$L_{av}(B40)$	$\bar{L}_{max}:\bar{L}_{min}$	CCT
L1	760 (0.72)	243 (0.4)	0.30	2.16	154	65	4	4002
L2	640 (0.43)	276 (0.16)	0.65	1.90	157	70	5	4039
L3	1116 (0.31)	143 (0.09)	0.69	2.03	74	24	16	3981
L4	416 (0.78)	125 (0.58)	0.32	1.74	78	30	6	6182
L5	697 (0.67)	225 (0.37)	0.36	2.13	146	60	4	5815
R1	604 (0.78)	201 (0.45)	0.37	2.19	129	53	4	2896
R2	333 (0.66)	156 (0.37)	0.45	1.63	106	55	4	2901
R3	312 (0.46)	64 (0.19)	0.62	1.69	47	16	9	2656
R4	389 (0.55)	136 (0.12)	0.66	2.19	72	29	6	3069
R5	285 (0.05)	27 (0.54)	1.56	1.74	29	15	10	2659
M1	1873 (0.50)	-	0.42	1.90	273	112	6	6669
M2	1312 (0.58)	-	0.43	1.79	196	76	6	2274
M3	388 (0.11)	-	0.81	1.23	80	36	4	5928
M4	220 (0.05)	-	0.96	0.82	35	18	6	1950
M5	329 (0.40)	-	0.62	1.92	57	26	5	-

All of relaxing settings were found to be at a narrow CCT range of approximately between 2,700K to 3,000K at an eye level, whereas in lively settings, a use of higher CCT (no less than 4,000K) were observed. Two lively settings (L4, and L5) were found with particularly high levels of CCT, which were close to 6,000K. What is important here is that such result did not only come from white lights. A number of the designers (L1, L4, and L5) included a use of coloured lighting for accent lighting.

In summary, this chapter explains recorded illumination characteristics of the fifteen light settings. Illuminances and its uniformity, luminance and its ratio and CCTs were the mainly recorded photometric and colorimetric variables in this chapter. Table 5.49 provides an overview of measured photometric and colorimetric characteristics of the fifteen light settings.

Chapter 6

Result and findings from the experiment: Part I

The controlled experiment has produced a large volume of the result and the findings, therefore, the results and the findings of the experiments are explained in the following three chapters. This chapter reports the results on perceived appearance, pleasantness and activation and their findings.

6.1 Appearance

As explained in Chapter 3, measured appearances of a space were self-assessed by six items of sematic differential scales (9-point rating). This section first explains the results of perceived appearances under lively, relaxing, and miscellaneous settings and the findings in this matter is discussed.

6.1.1 Lively settings

Lively setting 1

Figure 6.1 illustrate the results of the appearances under L1 setting. In order to remind what L1 setting was like, a general view of L1 setting was also provided in the figure.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	6	4	12	8	5	5	2	0	0	Dim
Uniform	2	0	8	7	7	8	8	0	1	Nonuniform
Uninteresting	0	2	1	1	5	11	18	2	2	Interesting
Chilly	0	2	6	8	8	10	6	2	0	Warm
Spacious	2	2	10	8	13	5	2	0	0	Confined
Dramatic	0	4	4	12	6	3	7	6	0	Diffuse

Figure 6.1. Self-assessed appearance of a space under L1 setting. Left figure shows measured frequencies of each item and right figure shows a general view of L1 setting.

As can be seen from the figure, most number of participants described the space as 'moderately bright' and only few described it as 'dim'. In terms of perceived uniformity of lighting, the result showed a wide spread in the perceptions between 'moderately uniform' to 'moderately nonuniform'. The setting clearly resulted in the participants to have a degree of above neutral to moderate level of 'visual interest'. Perceived colour appearance varied from 'moderately chilly' to 'moderately warm', which would be explained by the fact that some of the lights in the setting continuously changed its colors from saturated blue, red and green. Again, a wide spread in the perception of diffuseness was noticed varying from 'slightly dramatic' to 'very much diffuse'. Lastly, although most number of participants described neutral an appearance of spaciousness, a significant number of them described it as being 'moderately spaciousness'.

<u>Lively setting 2</u>

The same formats of figures (see Figure 6.2) were used to describe the results of perceived appearance under lively setting 2. The space was clearly perceived as being bright with high frequencies on 'very much bright' and 'slightly bright'. It was also perceived as being moderately uniform by most numbers of the participants. In terms of visual interest, a wide spread in the perception, varied from 'moderately uninteresting' to 'moderately interesting' was found with highest frequency in the neutral. Colour appearance of the space was noticed between high frequencies of 'slightly chilly' and 'neutral'. It was also perceived as 'being moderately spacious' and 'slightly spacious' by the most number of respondents. The space was described as being neutral in its diffuseness by the most numbers but also a significant number of respondents described it as being above 'moderately diffuse'.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	8	12	5	11	2	4	0	0	0	Dim
Uniform	4	8	10	6	3	3	6	2	0	Nonuniform
Uninteresting	2	2	6	8	10	8	6	0	0	Interesting
Chilly	2	0	8	13	9	8	0	2	0	Warm
Spacious	0	8	11	11	8	4	0	0	0	Confined
Dramatic	0	0	5	6	12	3	7	5	4	Diffuse

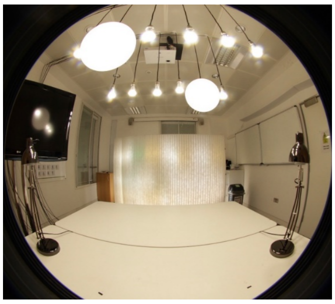


Figure 6.2. Self-assessed appearance of a space under L2 setting. Left figure shows measured frequencies of each item and right figure shows a general view of L2 setting.

<u>Lively setting 3</u>

Perceived appearance of the space under L3 setting with a general view of the space is shown in Figure 6.3. Under L3, participants described the space as being mostly bright and the perception varied from 'completely bright' to 'slightly dim'. One possible reason for such wide spread in the brightness perception is the fact that the light was intensely focused on the task area, where the participants made their assessment. Such an illumination pattern also resulted in a wide range of perception of uniformity. The most number of people described that they felt a degree of slightly to moderately level of visual interest although a significant number of people were quite opposite in that perception. Colour appearance of the space was mostly described as being ‘moderately chilly’. The focused illumination on the task area resulted in the space being mostly perceived by being ‘slightly confined’. Lastly, the space was perceived as ‘moderately to slightly dramatic’ by the most number of participants.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	8	5	9	9	3	6	0	0	0	Dim
Uniform	4	2	4	9	0	5	8	8	0	Nonuniform
Uninteresting	2	6	4	5	4	13	6	0	0	Interesting
Chilly	0	8	14	11	2	3	2	0	0	Warm
Spacious	0	2	6	4	4	5	13	4	2	Confined
Dramatic	2	2	10	9	8	6	3	0	0	Diffuse

Figure 6.3. Self-assessed appearance of a space under L3 setting. Left figure shows measured frequencies of each item and right figure shows a general view of L3 setting.

Lively setting 4

Figure 6.4 illustrates a general view of L4 and the perceived appearance under L4 setting. As can be seen from the figure, the space was perceived as being ‘completely bright’ to ‘moderately bright’. The result also showed a high perception in uniformity of lighting, with the highest frequency in ‘very much uniform’. Most of the participants described the space as being visually interesting above the moderate level. The space was also perceived as being ‘moderately spacious’ by the most number of participants. Overall, the results showed that L4 setting created a number of positive perceptions in the appearance of the space.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	15	9	15	1	0	0	2	0	0	Dim
Uniform	8	11	9	4	6	2	2	0	0	Nonuniform
Uninteresting	0	3	1	3	5	4	14	12	0	Interesting
Chilly	6	13	11	10	0	2	0	0	0	Warm
Spacious	5	11	17	5	3	0	1	0	0	Confined
Dramatic	0	1	5	14	9	5	4	4	0	Diffuse

Figure 6.4. Self-assessed appearance of a space under L4 setting. Left figure shows measured frequencies of each item and right figure shows a general view of L4 setting.

Lively setting 5

The self-assessed appearance of the space under L5 setting is shown in Figure 6.5 with a general view of the space. Most participants described the space as being ‘completely bright’. In terms of perceived visual interest from the space, the space was mostly perceived as being either ‘neutral’ or ‘slightly interesting’, although a significant number of participants also described it as visually uninteresting. Apart from the perceived visual interest, the space was perceived in a very similar way to the space under L4. The L5 setting also resulted in the space being perceived as spacious.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	17	13	6	3	3	0	0	0	0	Dim
Uniform	12	9	11	5	1	4	0	0	0	Nonuniform
Uninteresting	6	4	6	3	9	10	0	0	4	Interesting
Chilly	7	11	9	9	6	0	0	0	0	Warm
Spacious	10	8	10	11	3	0	0	0	0	Confined
Dramatic	0	0	10	6	4	4	8	4	6	Diffuse

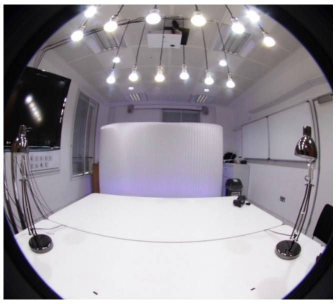


Figure 6.5. Self-assessed appearance of a space under L5 setting. Left figure shows measured frequencies of each item and right figure shows a general view of L5 setting.

6.1.2 Relaxing settings

Relaxing setting 1

Figure 6.6 shows the self-assessed appearance under R1 as well as the general view of the space. The space was perceived by most number of participants as being ‘moderately to slightly bright’. Perceived uniformity under R1 was widely spread from uniform to nonuniform with highest frequency in ‘slightly nonuniform’. The result indicated that most participants rated the space as being moderately interesting. Perceived colour appearance of the space was mostly in between neutral to slightly warm. In terms of perceived spaciousness, most number of participants rated it as being neutral.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	0	2	13	13	6	6	0	2	0	Dim
Uniform	1	5	6	7	5	12	2	4	0	Nonuniform
Uninteresting	2	4	2	2	4	6	18	4	0	Interesting
Chilly	0	2	7	3	10	10	4	4	2	Warm
Spacious	0	5	7	4	14	8	4	0	0	Confined
Dramatic	0	1	9	11	5	6	8	2	0	Diffuse

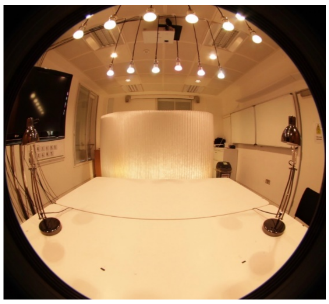


Figure 6.6. Self-assessed appearance of a space under R1 setting. Left figure shows measured frequencies of each item and right figure shows a general view of R1 setting.

Relaxing setting 2

Perceived appearance of the space under R2 is shown in Figure 6.7 with a general view of the space. Unlike the earlier spaces, the space was appeared as being 'slightly dim' by the most number of participants. Although the space was appeared as being slightly to moderately uniform, there were also some participants who described the space as moderately nonuniform. The space evoked a degree of 'visual interest' as it was described as 'moderately interesting' with highest frequency. In terms of perceived spaciousness, a perception was in a range of 'moderately spacious' to 'slightly confined'. Lastly, the space was mostly appeared as being neutral in diffuseness.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	1	1	4	4	7	16	5	4	0	Dim
Uniform	2	2	8	12	4	4	8	2	0	Nonuniform
Uninteresting	2	2	0	3	5	5	15	6	4	Interesting
Chilly	0	0	0	2	0	4	22	9	5	Warm
Spacious	2	2	10	6	10	10	2	0	0	Confined
Dramatic	0	0	4	8	10	9	9	0	2	Diffuse

Figure 6.7. Self-assessed appearance of a space under R2 setting. Left figure shows measured frequencies of each item and right figure shows a general view of R2 setting.

Relaxing setting 3

Figure 6.8 shows the self-assessed appearance of the space under R3 setting. As can be seen from the figure, the space was appeared as slightly to moderately dim by the most number of participants. The space was also appeared as moderately nonuniform. In terms of visual interest, although many of them described the space as being neutral, a high number of participants also described it as moderately interesting. The space appeared as moderately to very warm. In terms of spaciousness, the space appeared as slightly confined to many respondents.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	0	2	0	0	0	18	18	4	0	Dim
Uniform	0	2	0	4	6	7	15	8	0	Nonuniform
Uninteresting	0	2	7	3	18	4	16	2	0	Interesting
Chilly	0	0	0	2	2	6	18	11	3	Warm
Spacious	0	0	0	4	12	16	6	2	2	Confined
Dramatic	0	0	7	7	9	9	6	4	0	Diffuse

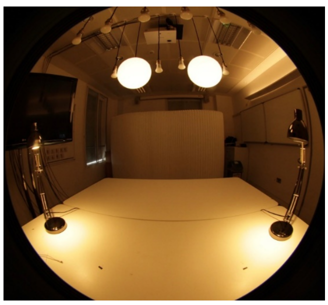


Figure 6.8. Self-assessed appearance of a space under R3 setting. Left figure shows measured frequencies of each item and right figure shows a general view of R3 setting.

<u>Relaxing setting 4</u>

The result of self-assessed appearance of the space under R4 setting is shown in Figure 6.9 with a general view of the space. The result showed the space appeared as moderately dim with highest frequency, but there were also a number of participants who described the space as being bright above the neutral level. Illumination uniformity appeared to be neutral to slightly nonuniform under R4 setting. The space was described as highly visually interesting as 27 out of 42 participants rated it as moderately interesting or even higher than that. The colour appearance of the space was mostly described as moderately warm to completely warm. The result indicated that the space appeared to be confined up to a slight to a moderate level. Perception of visual diffuseness was widely spread from completely dramatic to completely diffuse.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	0	2	5	7	7	7	14	0	0	Dim
Uniform	0	0	3	5	10	10	8	4	0	Nonuniform
Uninteresting	0	0	4	2	3	5	15	11	2	Interesting
Chilly	0	0	0	1	1	9	17	8	6	Warm
Spacious	0	0	4	6	6	14	10	2	0	Confined
Dramatic	2	8	4	4	6	8	4	4	2	Diffuse

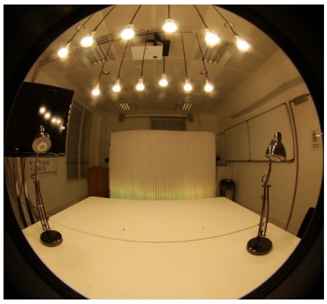


Figure 6.9. Self-assessed appearance of a space under R4 setting. Left figure shows measured frequencies of each item and right figure shows a general view of R4 setting.

<u>Relaxing setting 5</u>

The appearance of the space under R5 setting is shown in Figure 6.10. As can be seen from the figure, the space mostly appeared as moderately dim, nonuniform, and interesting by the highest number of participants. The colour appearance under R5 setting was described as moderately and very warm. Many of participants described that the space looked slightly to moderately confined as well as looking diffuse.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	0	0	3	1	0	6	26	6	0	Dim
Uniform	0	3	5	2	4	6	13	9	0	Nonuniform
Uninteresting	2	0	1	1	6	10	18	3	1	Interesting
Chilly	0	0	0	3	3	6	12	14	4	Warm
Spacious	0	3	3	1	9	12	13	1	0	Confined
Dramatic	1	2	5	7	5	10	8	2	2	Diffuse

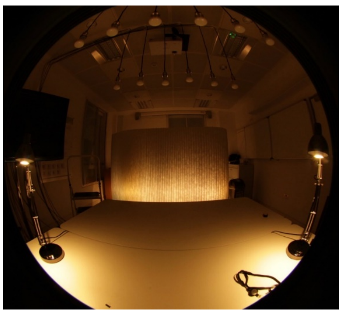


Figure 6.10. Self-assessed appearance of a space under R5 setting. Left figure shows measured frequencies of each item and right figure shows a general view of R5 setting.

6.1.3 Miscellaneous settings

<u>Miscellaneous setting 1</u>

Figure 6.11 shows the self-assessed appearances of the space under M1 setting with a general view of the space. As intended, the space was assessed as completely bright by most of the respondents. Although 12 out of 42 participants rated the space as neither uninteresting nor interesting, 10 out of 42 participants described the space as completely uninteresting. A higher level of perceived uniformity and perceived spaciousness was also noticed. The colour of the space was appeared as moderately to completely chilly.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	34	4	2	0	0	0	0	0	0	Dim
Uniform	12	11	11	2	1	1	2	0	0	Nonuniform
Uninteresting	10	4	4	2	12	2	1	3	2	Interesting
Chilly	8	12	10	4	4	0	2	0	0	Warm
Spacious	10	10	11	5	0	1	1	2	0	Confined
Dramatic	4	4	0	2	9	3	3	9	6	Diffuse

Figure 6.11. Self-assessed appearance of a space under M1 setting. Left figure shows measured frequencies of each item and right figure shows a general view of M1 setting.

<u>Miscellaneous setting 2</u>

The self-rated appearances of the space under M2 setting is shown in Figure 6.12. The brightness perception under M2 settings was mostly in a range of very much bright to neutral in brightness. One noticeable result compared to M1 is that the space was rated more visually interesting than M1 setting, which suggests that somehow participants felt more under a warm colour appearance than a chilly appearance. Unlike M1 setting the space was mostly perceived as slightly confined, too. In terms of perceived diffuseness, it was noticed that many of participants rated the space as neutral to slightly diffuse.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	0	8	10	6	10	4	4	0	0	Dim
Uniform	2	4	11	11	4	4	6	0	0	Nonuniform
Uninteresting	1	3	6	4	6	10	6	5	1	Interesting
Chilly	0	0	0	0	0	6	6	15	15	Warm
Spacious	2	2	6	4	8	12	6	2	0	Confined
Dramatic	0	4	2	2	10	16	0	4	4	Diffuse

Figure 6.12. Self-assessed appearance of a space under M2 setting. Left figure shows measured frequencies of each item and right figure shows a general view of M2 setting.

Miscellaneous setting 3

The result of self-assessed appearances of the space under M3 setting is shown in Figure 6.13 with a general view of the space. The result indicated that the space was mainly appeared as moderately dim and very much nonuniform by most of the participants. In terms of visual interest, many participants rated the space as slightly interesting and neutral in interest. The space was mostly appeared as moderately chilly as expected with the uses of high CCT lamps. Lastly, the space was perceived as being dramatic with highest frequency on the moderate level.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	0	0	0	2	2	4	24	6	4	Dim
Uniform	0	0	0	5	3	2	8	22	2	Nonuniform
Uninteresting	1	3	3	3	8	14	4	2	4	Interesting
Chilly	0	6	16	8	5	3	3	1	0	Warm
Spacious	0	0	2	2	12	12	10	2	2	Confined
Dramatic	0	6	10	8	8	4	6	0	0	Diffuse

Figure 6.13. Self-assessed appearance of a space under M3 setting. Left figure shows measured frequencies of each item and right figure shows a general view of M3 setting.

Miscellaneous setting 4

Figure 6.14 shows the results of the self-rated appearance of the space under M4 setting. The results indicated that the space was perceived as both very much dim and nonuniform by most of participants. In terms of visual interest, it was found that highest number of participants rated the space as ‘moderately interesting’ with the second highest frequency being slightly interesting. As expected, a perception of completely warm to very warm was noticed to describe the colour appearance of the space. Lastly, the space was mostly described as moderately confined.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	0	0	0	0	0	0	6	30	6	Dim
Uniform	2	3	3	3	2	3	8	13	5	Nonuniform
Uninteresting	0	2	5	5	7	9	10	2	2	Interesting
Chilly	0	0	2	0	0	2	4	16	18	Warm
Spacious	0	0	0	0	2	8	24	4	4	Confined
Dramatic	0	6	8	6	8	2	4	6	2	Diffuse

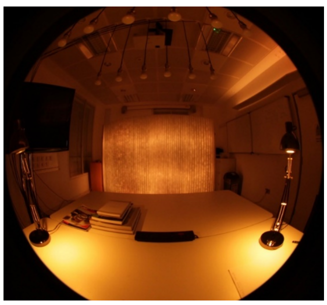


Figure 6.14. Self-assessed appearance of a space under M4 setting. Left figure shows measured frequencies of each item and right figure shows a general view of M4 setting.

<u>Miscellaneous setting 5</u>

Lastly, the results of the self-assessed appearance of the space under M5 setting is shown in Figure 6.15 with a general view of the space. As intended, most of participants rated the space as completely visually interesting. Other than the perception of visual interest, the space was mostly perceived as moderately dim and highly nonuniform. In terms of colour appearance of the space, many of the participants described the space as neutral, slightly warm and moderately warm. Lastly, the space was described as highly dramatic again as expected with the high contrast in the uses of colours.

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	0	1	3	4	5	7	20	2	0	Dim
Uniform	0	0	0	2	0	6	14	6	14	Nonuniform
Uninteresting	0	0	2	0	4	6	6	8	16	Interesting
Chilly	0	0	4	6	10	10	12	0	0	Warm
Spacious	0	2	1	1	10	6	16	4	2	Confined
Dramatic	10	12	6	8	4	0	0	2	0	Diffuse

Figure 6.15. Self-assessed appearance of a space under M5 setting. Left figure shows measured frequencies of each item and right figure shows a general view of M5 setting.

6.1.4 Findings from perceived appearance

This chapter has, so far, explained the results of the self-assessed appearances of the space under fifteen light settings. The study then compared such perceptions with several illumination parameters (obtained and explained in Chapter 5) in order to investigate as to whether (1) perceived appearances of the space are well explained by findings from previous literature and (2) if not, what elements of luminous environments in this study have caused such differences.

In order to analyse perceived brightness and its relations with the luminous environments, there was a need to organise fifteen settings in an order from most bright to most dim. Since the self-rating of the appearance was made with the categorical data, direct comparison among fifteen settings was difficult. Therefore, mean values of perceived brightness under fifteen settings were first calculated as a starting point. Figure 6.16 indicates fifteen levels of perceived brightness by the order of mean values with four photometric charactersitics. It should also be noted that the presented orders in Figure 6.16 only provided an overall impression of the perceived brightness not the statistical differences among the settings. For example, participants under L2 setting showed higher average value of perceived brightness than the space under L1 and L3 setting which does not necessarily mean that their perception of brightness was different with a strong statistical significance.

Brightness

Setting	1 Bright	2	3	4	5 Neutral	6	7	8	9 Dim	Mean	E_{task}	L_{av} (B40)	L_{av} (B40+task)	MRSE
M1	34	4	2	0	0	0	0	0	0	Mean:1.2	1873	118	194	273
L5	17	13	6	3	3	0	0	0	0	Mean: 2.1	697	61	118	146
L4	15	9	15	1	0	0	2	0	0	Mean: 2.2	416	34	54	78
L2	8	12	5	11	2	4	0	0	0	Mean: 3	640	74	103	157
L3	8	5	9	9	3	6	0	0	0	Mean: 3.6	760	71	80	154
L1	6	4	12	8	5	5	2	0	0	Mean: 3.6	1116	22	72	74
M2	0	8	10	6	10	4	4	0	0	Mean: 4.1	1312	81	139	196
R1	0	2	13	13	6	6	0	2	0	Mean: 4.2	604	61	76	129
R4	0	2	5	7	7	7	14	0	0	Mean: 5.3	389	29	43	72
R2	1	1	4	4	7	16	5	4	0	Mean: 5.4	333	63	66	106
M5	0	1	3	4	5	7	20	2	0	Mean: 6.0	329	26	35	57
R3	0	2	0	0	0	18	18	4	0	Mean: 6.4	312	14	32	47
R5	0	0	3	1	0	6	26	6	0	Mean: 6.6	285	15	25	29
M3	0	0	0	2	2	4	24	6	4	Mean: 7	388	59	71	84
M4	0	0	0	0	0	0	6	30	6	Mean: 8	220	18	27	35

Figure 6.16. A graphical presentation of mean values of appeared brightness of the room under fifteen settings. Four photometric characteristics of the settings were also provided on the right-hand side of the figure. Lively settings were coded in green, relating settings were coded in red, and miscellaneous settings were coded in blue on the left-hand side of the figure

In order to ensure minimum required level of brightness for a visual task, many lighting codes, recommendations have stated 300 lx or 500 lx of maintained illuminance level on the task area (E_{task}). The study compared perceived brightness under fifteen settings with the measured E_{task} values, as shown in Figure 6.17. As can be seen from the figure, except for L4, R2, R3, and R5, all of the designers' inspired settings achieved higher than 500 lx on the task area, and also perceived as generally bright (based on the average of perceived brightness). Average values of perceived brightness under R2 and R4 were also quite close to being neutral, which would lead to an assumption that both spaces were in an acceptable range of brightness as a workspace. Under R3 and R5, table lamps were the main light sources for the task area and therefore it would be understandable to have lower perception of brightness. Then, is E_{task} be a good indicator of our perception of brightness? A regression analysis between E_{task} and perceived brightness showed that E_{task} accounted for 47.2% of explained variation/total variation. The study does not intend to suggest that the linear equation could predict our perception of brightness but having high % of explained variance would provide an idea of whether such parameter can be regarded as a good indicator of our perceived brightness. According to the result, L3, L4, M1, and M2 settings, particularly, evoked rather unusual perception of brightness.

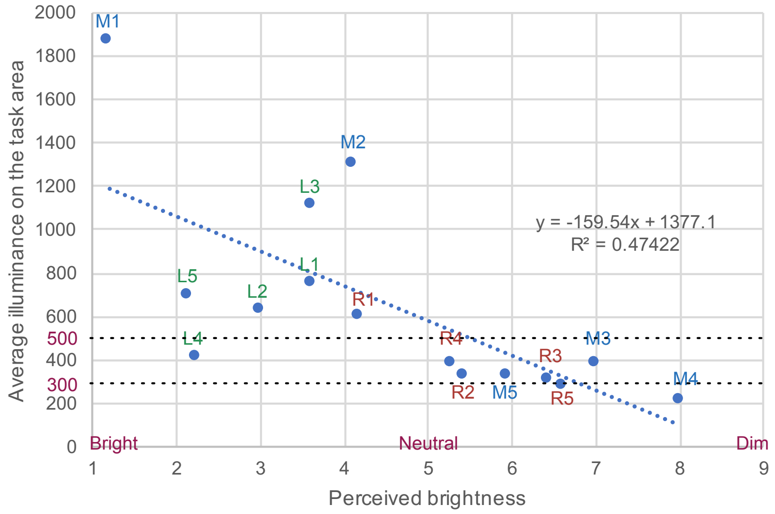


Figure 6.17. Scatter plot of perceived brightness vs. E_{task} with a regression line (blue dotted line). Black dotted lines indicate 300 lx, and 500 lx. For visual clarity, lively settings were marked green, relaxing settings were marked red, and miscellaneous settings were marked blue.

The study then compared perceived brightness with average luminance of the horizontal band of width 40° ($L_{av}(B40)$), as to whether findings from Loe *et al.* (1994) were well replicated in this study. Figure 6.18 shows a scatter plot of perceived brightness and $L_{av}(B40)$. The result suggests that perceived brightness was not well explained by obtained $L_{av}(B40)$ values. Several settings such as L3, L4, and M3 showed huge variations in perceived brightness although measured $L_{av}(B40)$ values were reasonably similar, 30cd/m^2.

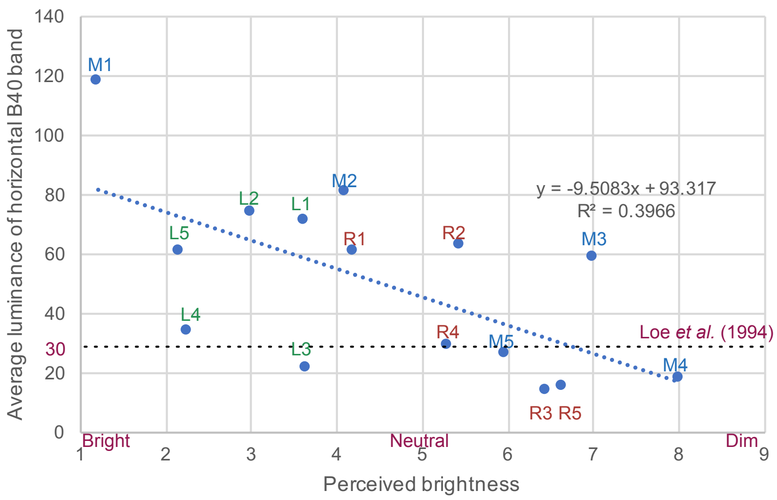


Figure 6.18. Scatter plot of perceived brightness vs.$L_{av}(B40)$ with a regression line

(blue dotted line). Black dotted line indicates a value of 30cd/m^2 of $L_{av}(B40)$, which was suggested to be a point where perception of brightness changes from generally dim to generally bright.

Moreover, obtained R^2 value also only accounted for 39.1% of explained variation/total variation. However, the research designs adopted in two studies were completely different to be directly compared. At this study, participants made their assessment of brightness while sitting on the task area with their own tasks, whereas under Loe *et al.* (1994)'s study, participants rated their perceived brightness while they were standing on a room with no defined visual task. Therefore, the study has considered average luminance value that include the task area with the horizontal band of width 40°, defined as $L_{av}\ (B40 + task)$ in this study. Figure 6.19 shows a scatter plot of perceived brightness vs. $L_{av}\ (B40 + task)$, with a regression line. First, the result showed a higher R^2 (0.556) than the two earlier parameters. Although the study does not intend to conclude that such linear equation can be used to predict our perceived brightness, it could be argued that $L_{av}\ (B40 + task)$ is a more efficient indicator of our perceived brightness than the earlier two parameters, particularly at a workspace.

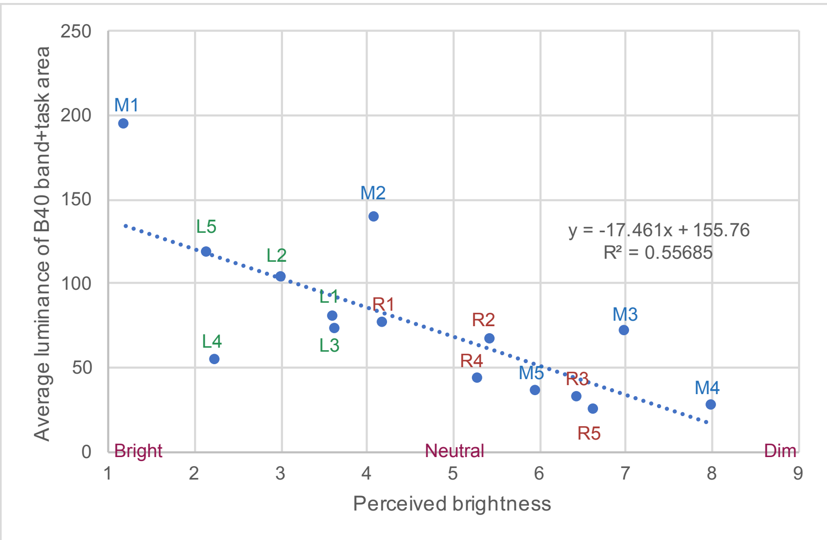


Figure 6.19. Scatter plot of perceived brightness vs. $L_{av}\ (B40 + task)$, with a regression line. Lively settings were marked green, relaxing settings were marked red, and miscellaneous settings were marked blue.

Lastly, MRSE (lm/m^2) was compared with perceived brightness, as to whether suggestion of Cuttle (2010) would be replicated in the study. Figure 7.20 shows a scatter plot diagram of perceived brightness vs. MRSE. Cuttle (2010) suggested two values of MRSE, 30 lm/m^2 and 100 lm/m^2 as reference values for a practical use. According to his argument, a space with higher than 100 lm/m^2 of MRSE would appear to be adequately bright whereas a space with lower than 30 lm/m^2 of MRSE would appear to be dim. In Figure 6.20, his two reference values are displayed in black dotted lines. The result shows huge variation of perceived brightness under L3, L4, R3 and M3 settings although the obtained MRSE values were in a similar range.

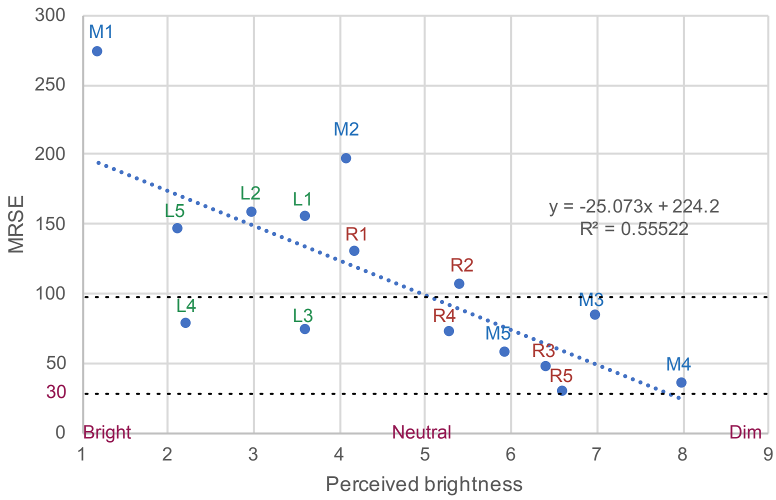


Figure 6.20. Scatter plot of perceived brightness vs. MRSE with a regression line (blue dotted line). Black dotted lines indicate values of 30 lm/m2 and 100 lm/m2, which are suggested reference values from Cuttle (2010).

By comparing the photometric characteristics and perceived brightness under 15 settings, several exceptional cases were noticed which photometric characteristics did not explain self-rated brightness. One is that participants described the space under L4, particularly bright considering its photometric characteristics. Whereas M2 and M3 settings appeared dimmer than other settings with similar photometric characteristics. Regarding L4 setting, the result indicates that somehow creating a cove effect with saturated blue colour combined with the uses of the recessed ceiling luminaires at a CCT of 5,000K would result in a very bright appearance of the space.

<u>Visual interest</u>

The same method of organizing fifteen settings by perceived level of brightness was applied in perception of visual interest. Figure 6.21 shows perceived levels of visual interest under fifteen settings by a rank order of their mean values. As can be seen from the figure, participants' perceptions of visual interest were much more unclear than perceived brightness. There could be two possible explanations of such unclear pattern of the data. First, it could be said that human perception of visual interest is influenced by a greater number of unknown variables that are not associated with lighting than perceived brightness, and some examples of the unknown variables would be ‘furniture layout’, ‘physical decoration of a room’ and ‘cultural difference’. Second, it could be argued that most of the light settings used in this study resulted in only a small variation in perceived visual interest. Since there was no clear pattern found between photometric characteristics of the space and the perceived level of visual interest, the study has considered the results in a more descriptive way.

As can be seen from the figure below (Figure 6.21), it was noticed that relaxing settings were assessed as more visually interesting than most of lively settings. It could just be a coincidence but since the same lighting designers were involved to create both lively and relaxing settings, it could be argued that creating ‘emotionally lively’ and ‘visually attractive’ luminous environments is somehow more challenging than creating an atmosphere of ‘relaxing’ by lighting design. Another possible cause of most of the relaxing settings being assessed as attractive is higher visual preference of warm colours than chilly colours. Such argument is supported by the fact that participants felt more frequently a degree of ‘visual interest’ under M2 setting than M1 setting where only a few described it as interesting. Both settings used the same lighting design approach which only differed in CCT of the lamps. However, the same finding did not apply to the cases of M3 and M4 which shared the same lighting design approach but differed in CCTs.

	1 Uninteresting				5 Neutral				9 Interesting	Mean	L_{max}:L_{min}	E_{vec}:E_{Sr}	E_{back}:E_{task}
M5	0	0	2	0	4	6	6	8	16	Mean: 7.4	5	1.2	0.4
R4	0	0	4	2	3	5	15	11	2	Mean: 6.6	6	2	0.3
R5	2	0	1	1	6	10	18	3	1	Mean: 6.3	10	2.4	0.1
L4	0	3	1	3	5	4	14	12	0	Mean: 6.3	6	1.7	0.7
R2	2	2	0	3	5	5	15	6	4	Mean: 6.2	4	1.9	0.7
L1	0	2	1	1	5	11	18	2	2	Mean: 6.2	4	1.7	0.2
R1	2	4	2	2	4	6	18	4	0	Mean: 5.7	4	1.8	0.3
M4	0	2	5	5	7	9	10	2	2	Mean: 5.6	6	1.9	0.3
M3	1	3	3	3	8	14	4	2	4	Mean: 5.5	8	2	0.5
R3	0	2	7	3	18	4	16	2	0	Mean: 5.4	9	1.8	0.4
M2	1	3	6	4	6	10	6	5	1	Mean: 5.3	6	1.6	0.4
L2	2	2	6	8	10	8	6	0	0	Mean: 4.7	5	1.5	0.4
L3	2	6	4	5	4	13	6	0	0	Mean: 4.6	16	1.7	0.4
L5	6	4	6	3	9	10	0	0	4	Mean: 4.4	4	2	0.6
M1	10	4	4	2	12	2	1	3	2	Mean: 4	6	2	0.4

Figure 6.21. A graphical presentation of mean values of perceived visual interest of the room under fifteen settings. Four photometric characteristics of the settings were also provided on the right-hand side of the figure. Lively settings were coded in green, relating settings were coded in red, and miscellaneous settings were coded in blue on the left-hand side of the figure.

Lastly, the study has investigated whether some of the previous findings from the literature has been repeatedly found in this study or not. First, as exclusively explained in Chapter 2, Loe *et al.* (1994) suggested that both average luminance value in B40 band ($L_{av}(B40)$) and luminance ratio (L_{max}:L_{min}) could be used as an indicator of perceived appearance of 'visual lightness' and 'visual interest'. Table 6.1 shows a comparison between assumed visual appearances and perceived visual appearances under the fifteen lighting settings.

As clearly noticed in Table 6.1, Loe *et al*.'s suggestion of using the luminance ratio as a design indicator of 'visual interest' has not been validated in this study. 10 out of 15 settings rejected the assumptions made based on their idea. Although 4 out of 15 (1 being in-between 'rejected' and 'validated') settings, participants' perceived appearance of a space were matched by their suggested design assumptions, it seems that such is result is purely coincidental. The reason for this is obvious. First, their assumptions were made based on the experiments using a conference room, whereas in this study, the controlled experiments were conducted using a mock-up workspace environment. Therefore, it could be argued that their assumptions and suggestions of design indicators in relation with visual interest is not applicable to an office environment. Second, in their design indicators, there is no consideration of colour properties. M5 setting, for example, which appeared the most interesting out of the fifteen settings, contains many numbers of colour-changing features in the setting, and yet such characteristic was not included in the concept from Loe *et al*.'s suggestion.

In relation with their assumptions on perceived brightness, the finding shows that 11 out 15 settings validated their assumptions. Based on the result, it can be argued that their assumption on a perception of brightness is applicable than their assumption on perceived visual interest.

Table 6.1. A comparison between assumed visual appearances and perceived visual appearances based on Loe *et al*. (1994)''s lighting design indicators

	Lighting design indicators	Assumptions on visual appearances	Findings from the experiment (Assumptions validated or rejected)	
	L_{av} (B40), luminance ratio (L_{max}:L_{min})	Visual lightness, Visual interest	Mean perceived brightness (1 to 9)	Mean perceived visual interest
L1	71cd/m^2, 4.3:1	Bright and uninteresting	3.6, validated	6.2, rejected
L2	74cd/m^2, 5:1	Bright and uninteresting	3, validated	4.7, rejected
L3	22 cd/m^2, 16.2:1	Dim, and interesting	3.6, rejected	4.6, rejected
L4	34 cd/m^2, 5.6:1	Bright, and uninteresting	2.2, validated	6.3, rejected
L5	61 cd/m^2, 4:1	Bright, and uninteresting	2.1 validated	4.4, validated
R1	61 cd/m^2, 3.6:1	Bright, and uninteresting	4.2, validated	5.7, rejected
R2	63 cd/m^2, 3.9:1	Bright, and uninteresting	5.4, hard to argue that it's validated	6.2, rejected
R3	14 cd/m^2, 16.7:1	Dim, and interesting	6.4,validated	5.4, hard to argue that it's validated
R4	29 cd/m^2, 3.9:1	Dim to bright, and uninteresting	5.3, validated	6.6, rejected
R5	15 cd/m^2, 25.7:1	Dim and interesting	6.6, validated	6.3, validated
M1	118 cd/m^2, 7.7:1	Bright, and uninteresting	1.2 validated	4, validated
M2	81 cd/m^2, 8.6	Bright, and uninteresting	4.1, validated	5.3, rejected
M3	59 cd/m^2, 12:1	Bright, and uninteresting to interesting	7, rejected	5.5, validated
M4	18 cd/m^2, 9.7:1	Dim, and uninteresting	8, validated	5.6, rejected
M5	26 cd/m^2, 5.1:1	Dim to bright, and uninteresting	6, rejected	7.4, rejected

6.2 Pleasantness and activation

Perceived moods of the participants under fifteen light setting were measured by the 'Affect Grid', which is a single-item scale of pleasure (via 9 points) and activation (Russell *et al*., 1989). According to Russell *et al.* (1989), the Affect Grid was designed as a quick means of assessing human affect along the dimensions of *pleasant-unpleasant* and *activated-sleepy*. The scale has been known to potentially suitable for any study that requires judgements about affect (or emotion) of either descriptive or a subjective kind. A more detailed explanation was given in Chapter 3. Therefore, this section explains the results of the self-assessed pleasantness and activation levels under fifteen light settings with a form of the Affect Grid.

6.2.1 Lively settings

Lively setting 1

Figure 6.22 illustrate two figures, one on the left-hand side and another on the right-hand side. The figure on the left-hand side shows self-assessed pleasantness and activation levels on the Affect Grid under lively setting 1. In order to analyse a pattern of measured pleasantness and activation in a graphically clear way, the study represented the result by converting the responses into numbers, which is shown in the right-hand figure (in Figure 6.22). The mean value of perceived emotion was very close to being neutral (see 'X' in below Figure) The result in Figure 6.22 immediately gives an impression that lively setting 1 caused a wide range of feelings from unpleasantness to pleasantness and activation to sleepiness.

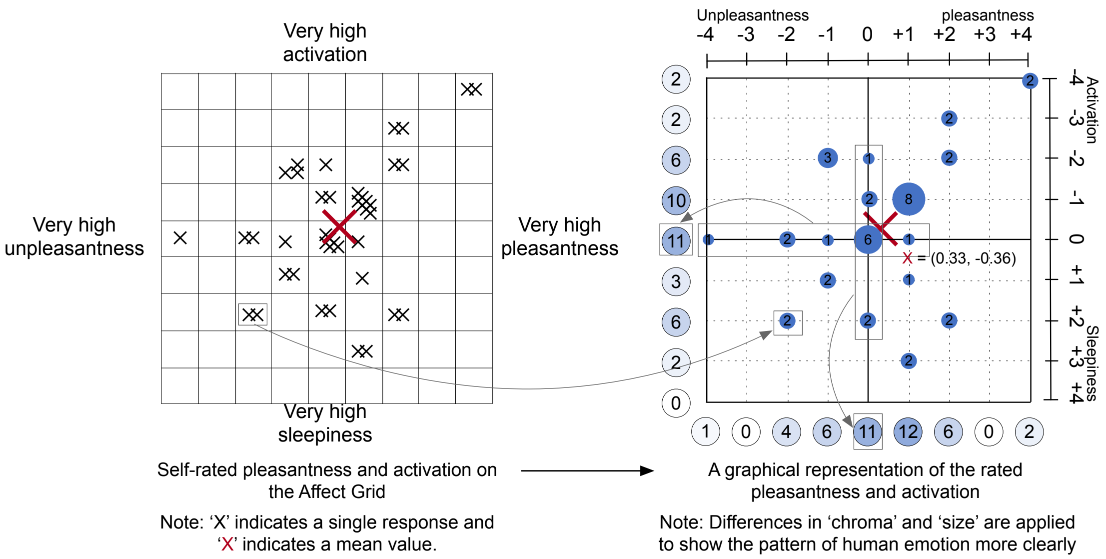


Figure 6.22. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under lively setting 1.

Lively setting 2

Perceived pleasantness/unpleasantness and activation/sleepiness under lively setting 2 is graphically presented in Figure 6.23. The result clearly indicates that a greater number of participants reported their feelings as highly activated than the people who felt sleepy under lively setting 2. Compare to the result of lively setting 1, such pattern is more visible. Only six out of forty-two participants felt a degree of sleepiness under lively setting 2. It seems that the designer achieved her target of making people being activated. However, it is difficult to claim that this light setting achieved another goal which was to create a feeling of pleasantness. As shown in Figure 6.23, the participants reported a wide spread of feelings from unpleasantness to pleasantness.

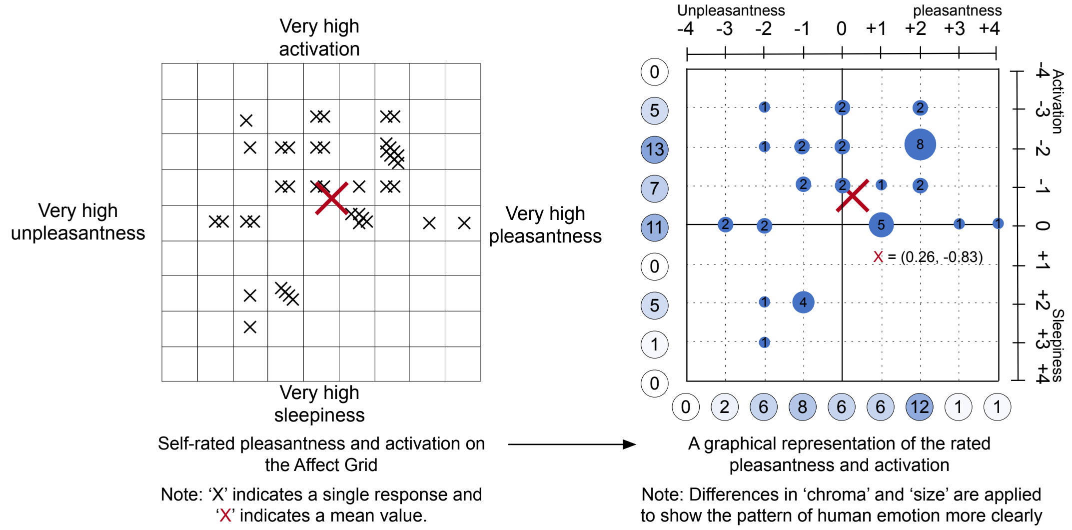


Figure 6.23. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under lively setting 2.

<u>Lively setting 3</u>

Figure 6.24 shows perceived pleasant/unpleasantness and activation/sleepiness level under lively setting 3. The mean value of perceived affect indicate that participants felt generally activated. An overall pattern of perceived emotions shown in Figure 6.24 gives an impression that the responses under this setting is quite similar to the feelings obtained under lively setting 2. Interesting, although only few participants (4 out of 42) reported their neutral feeling in pleasantness, mean value of pleasantness is close to being neutral due to a wide variability in responses on pleasantness.

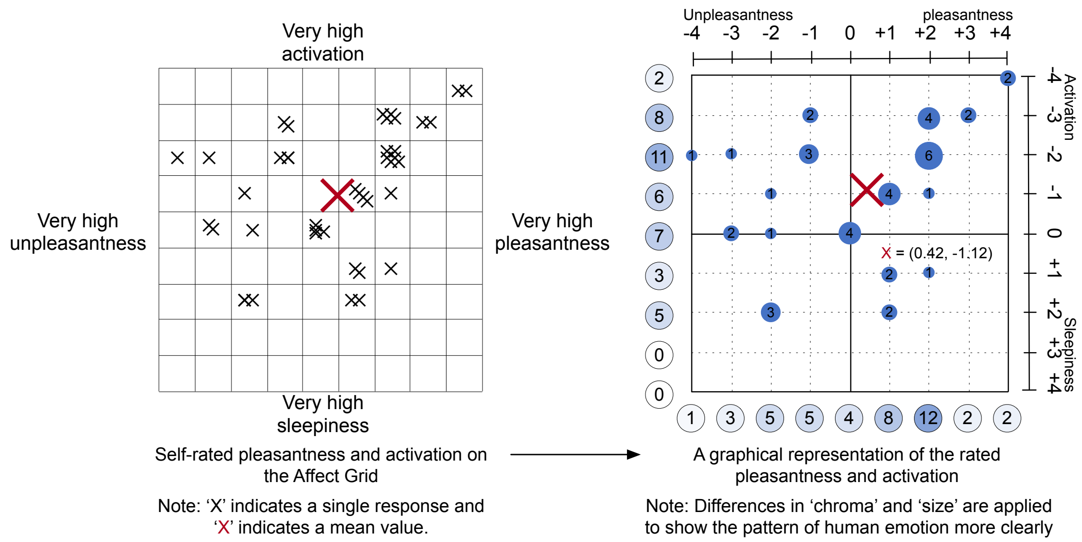


Figure 6.24. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under lively setting 3.

Lively setting 4

Figure 6.25 shows perceived pleasant/unpleasantness and activation/sleepiness level under lively setting 4. Unlike the earlier three cases, there was a clear trend that obtained feelings are mostly pleasant and activating. Therefore, the mean value of perceived emotion also indicates that a feeling of 'lively' is well achieved. Only 1 participant out of 42 reported a week degree of 'sleepiness'. Again, the result on lively setting 4 is impressive, considering that this setting appeared both very bright and very interesting to the participants. Overall, it can be stated that lively setting 4 has achieved its goal to create a feeling of intended 'lively'.

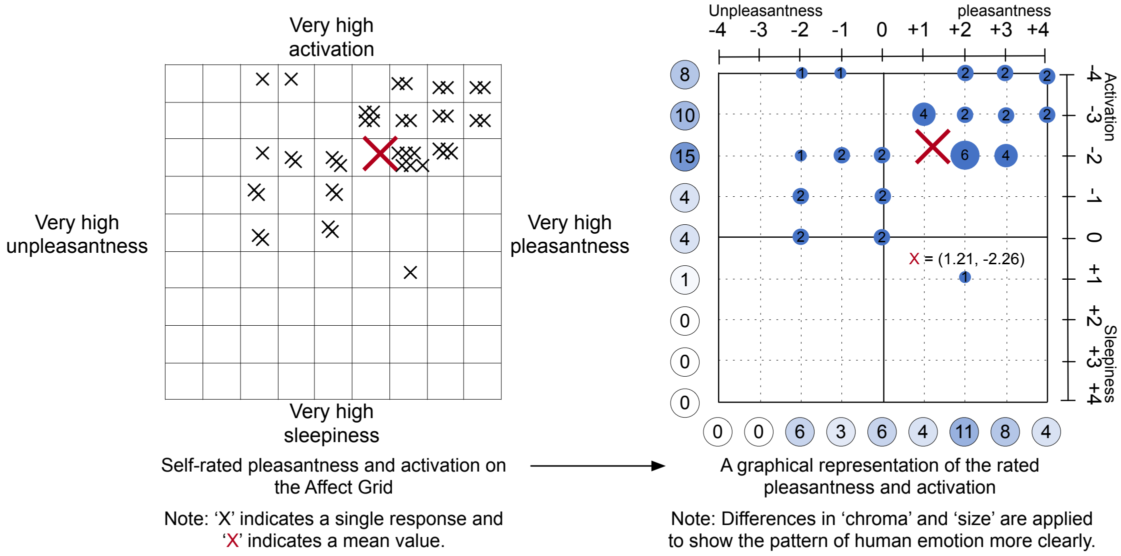


Figure 6.25. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under lively setting 4.

Lively setting 5

Perceived pleasantness/unpleasantness and activation/sleepiness under lively setting 5 is shown in Figure 6.26. A similar trend to the result from lively setting 4 is noticed. Again, the mean value of perceived emotion suggests that respondents reported generally a feeling of 'pleasant and activating'. Unlike the earlier results under lively setting 1,2, and 3, the results under L4 and L5 show a fewer level of variability in perceived activation level. It is clear that out of five lively settings, L4 and L5 were the ones that more successfully explored human emotion of pleasantness and activation during the controlled experiment.

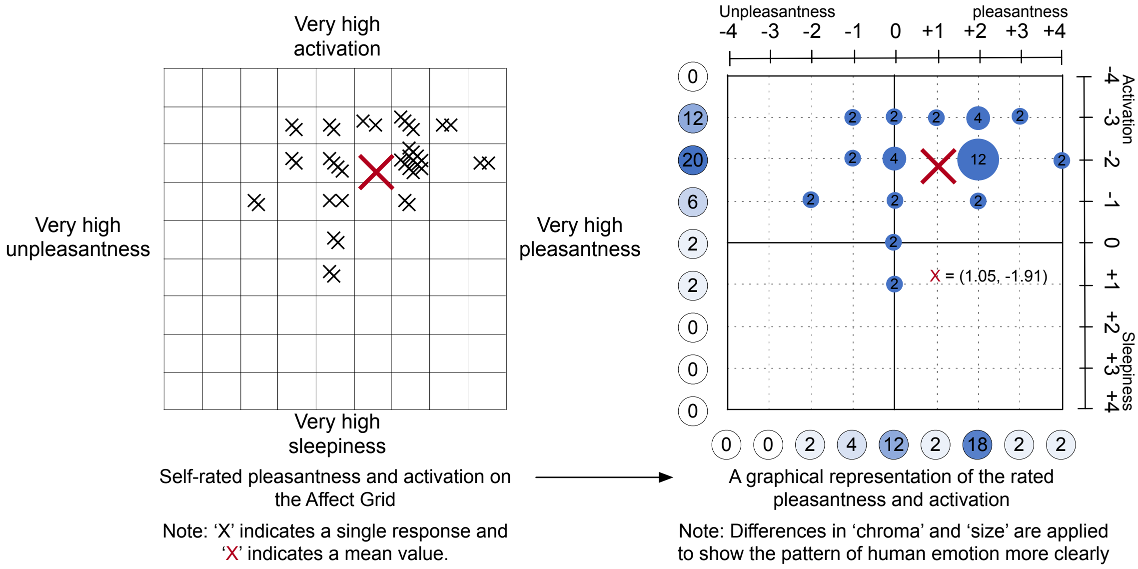


Figure 6.26. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under lively setting 5.

6.2.2 Relaxing settings

Relaxing setting 1

Perceived pleasantness/unpleasantness and activation/sleepiness under relaxing setting 1 is shown in Figure 6.27. The mean value of perceived emotion was very close to the being neutral and there does not seem to be a visible trend in their perceived emotions. Interestingly, even though the setting targeted to create a feeling of 'pleasantness' and 'sleepiness', there were more participants who felt a feeling of 'activated' under this setting.

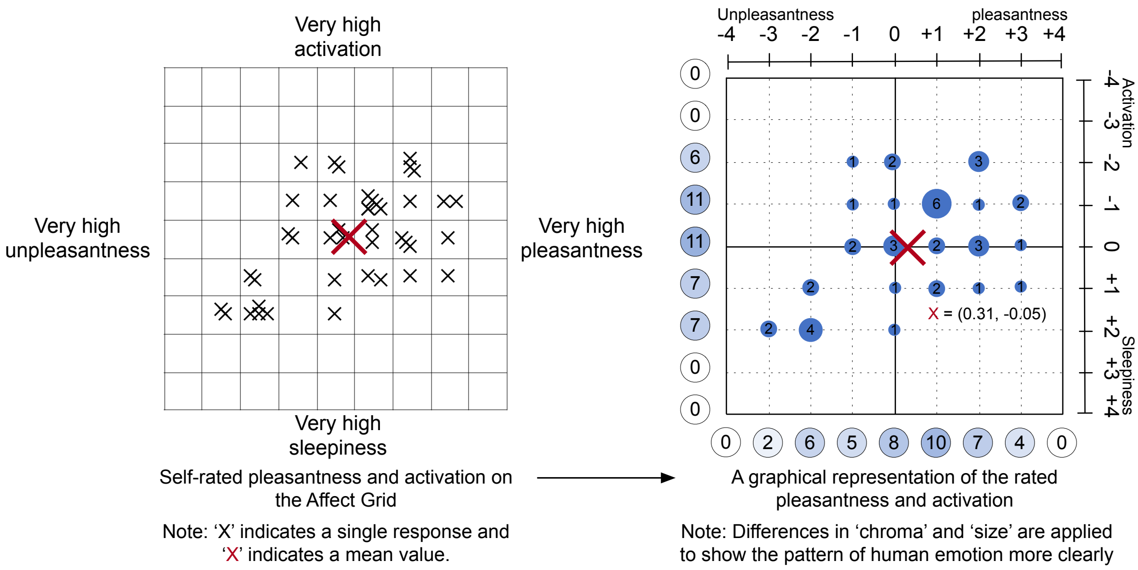


Figure 6.27. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under relaxing setting 1.

Relaxing setting 2

Figure 6.28 illustrates perceived feelings of pleasantness and activation under relaxing setting 2. Unlike the obtained feelings under relaxing setting 1, R2 resulted greater number of participants to feel sleepy under the experiment. Further, although there seems to be a variability to responses on pleasantness, half of the participants (21/42) reported a relatively high level of pleasantness (greater than or equal to +2 of pleasantness). The mean value of perceived emotions also indicates the same idea.

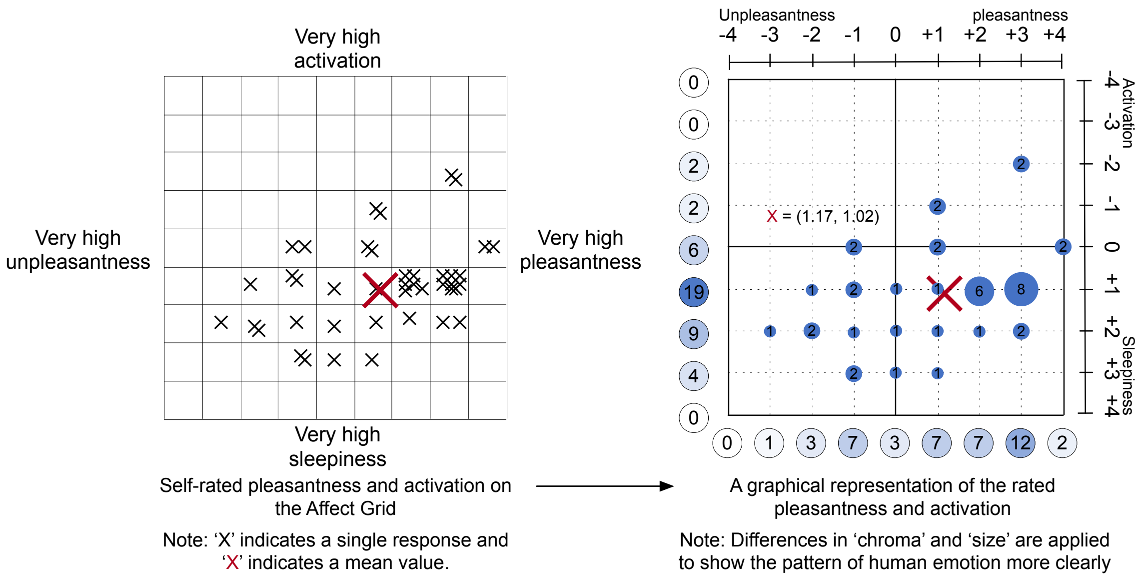


Figure 6.28. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under relaxing setting 2.

Relaxing setting 3

Figure 6.29 shows perceived pleasantness/unpleasantness and activation/sleepiness under relaxing setting 3. The result gives an immediate impression that majority of participants felt both 'pleasant' and 'sleepy' under this setting, which is also well described by the mean value of perceived emotion. It appears that both R2 and R3 setting created a feeling of intended 'relaxing'. Difference is that R3 setting evoked strong responses to sleepiness whereas R2 setting resulted relatively weaker responses to sleepiness.

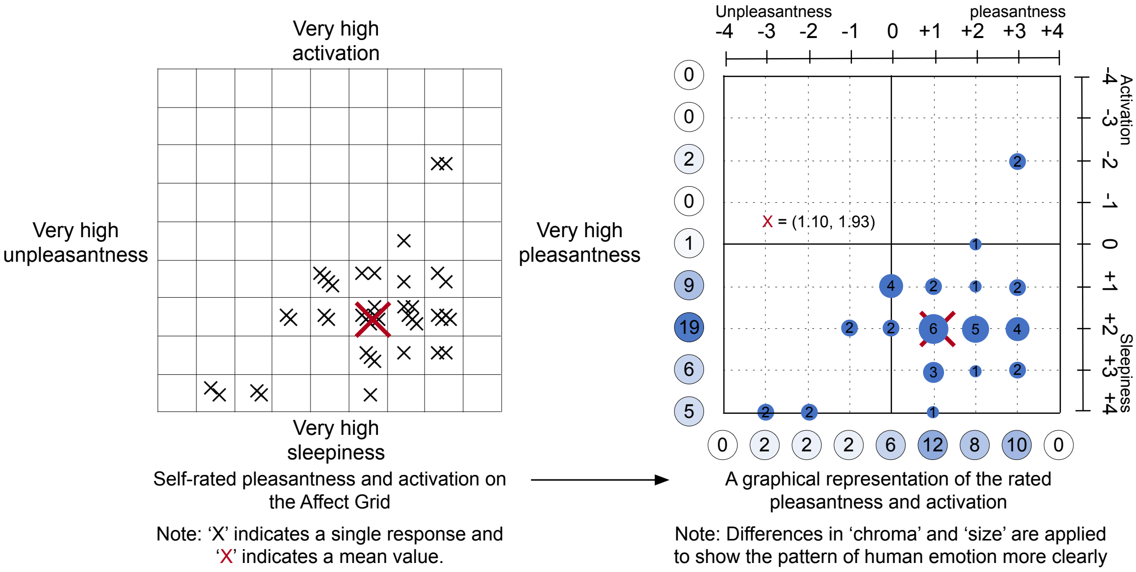


Figure 6.29. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under relaxing setting 3.

<u>Relaxing setting 4</u>

Figure 6.30 shows perceived pleasantness/unpleasantness and activation/sleepiness under relaxing setting 4. Although the mean value of perceived emotions indicate that participants felt close to neutral and sleepiness, in the real data shows that there was wide variability of responses to both pleasantness and sleepiness. As clearly seen in the figure, the mean value hardly matches what the obtained feelings under this setting were.

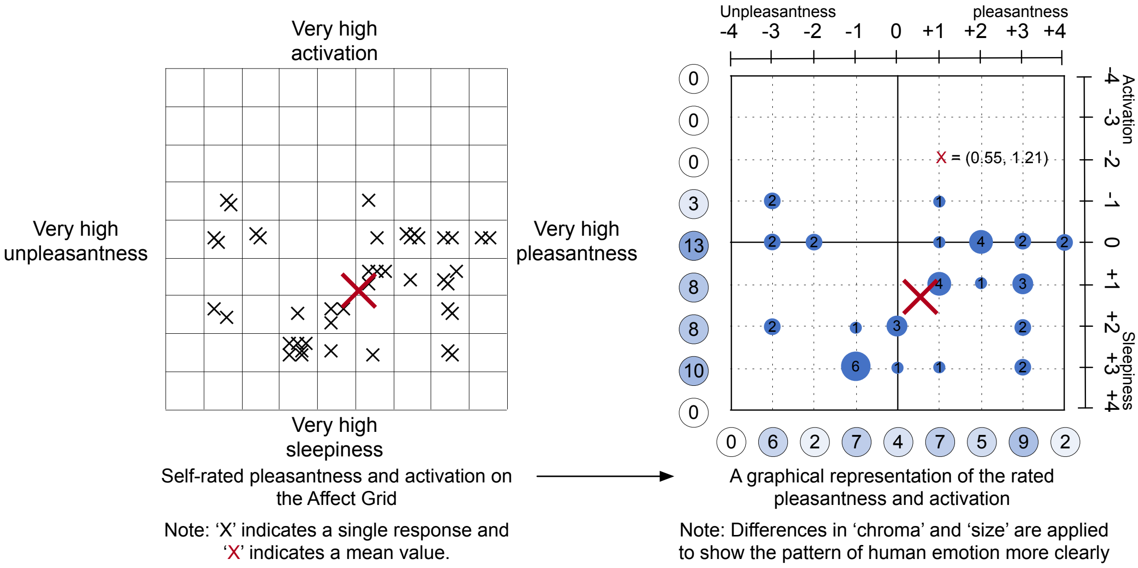


Figure 6.30. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under relaxing setting 4.

Relaxing setting 5

Figure 6.31 shows perceived pleasantness/unpleasantness and activation/sleepiness under relaxing setting 5. Similar to the obtained feelings under R3 setting, majority of participants felt both 'pleasant' and 'sleepy' under this setting and such characteristic is well indicated by the mean values of perceived emotion. By looking at the mean values, participant reported almost identical level of pleasantness and sleepiness to the ones from R3. Overall, it seems that R2, R3, and R5 achieved its goal of creating a feeling of 'relaxing', whereas R1 and R4 were not very effective in this matter.

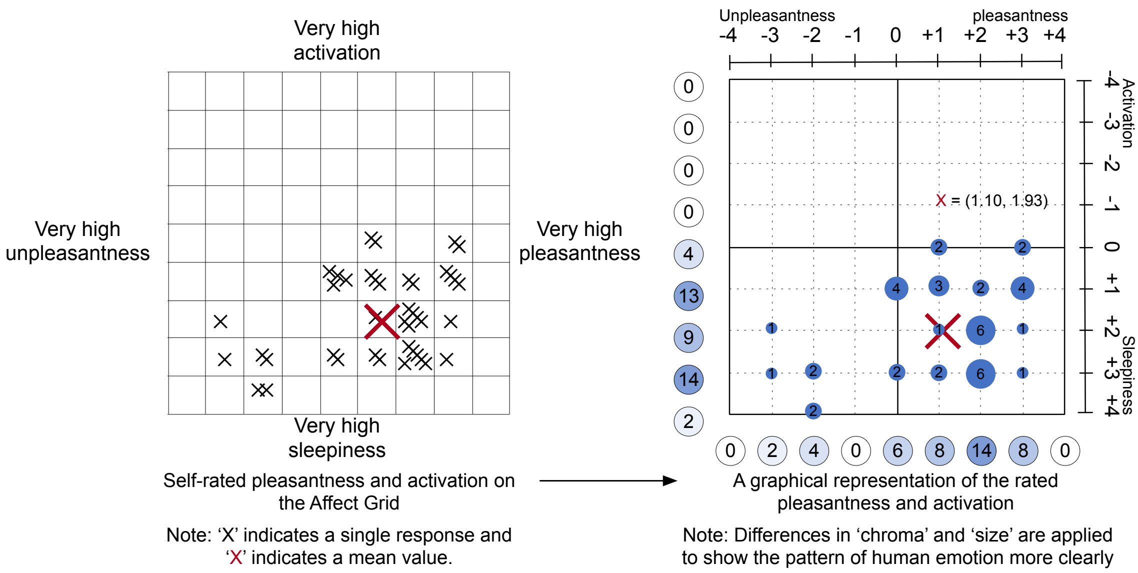


Figure 6.31. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under relaxing setting 5.

6.2.3 Miscellaneous settings

Miscellaneous setting 1

Self-rated pleasantness and sleepiness under miscellaneous setting 1 is shown in Figure 6.32. As can be seen from the below figure, there was a clear trend that strong responses to 'activating' were created by this setting. However, unlike the designers' settings, many numbers of participants (16 out of 42) reported a feeling of high unpleasantness (smaller than or equal to -2 of pleasantness). However, there was wide variability to responses on pleasantness in this setting.

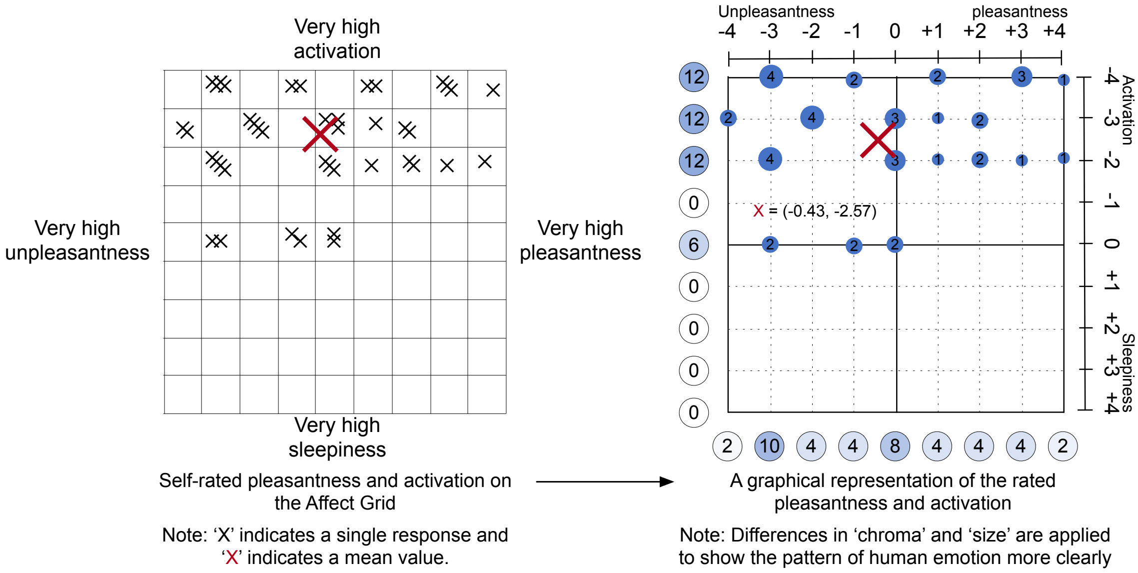


Figure 6.32. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under miscellaneous setting 1.

<u>Miscellaneous setting 2</u>

Self-rated pleasantness and sleepiness under miscellaneous setting 2 is shown in Figure 6.33. Compare to the obtained feelings under M1 setting, M2 setting clearly created more sleepiness atmosphere. The main difference between M1 and M2 setting in terms of illumination was the use of very high CCT lamps (M1) and the use of very low CCT lamps (M2). The result in Figure 6.33 suggests that varying a CCT from 6,500K to 2,000K can effectively lower subjective feelings of activeness and increase a feeling of sleepiness. Again, similar to M1 setting, a wide variability to responses on pleasantness was noticed.

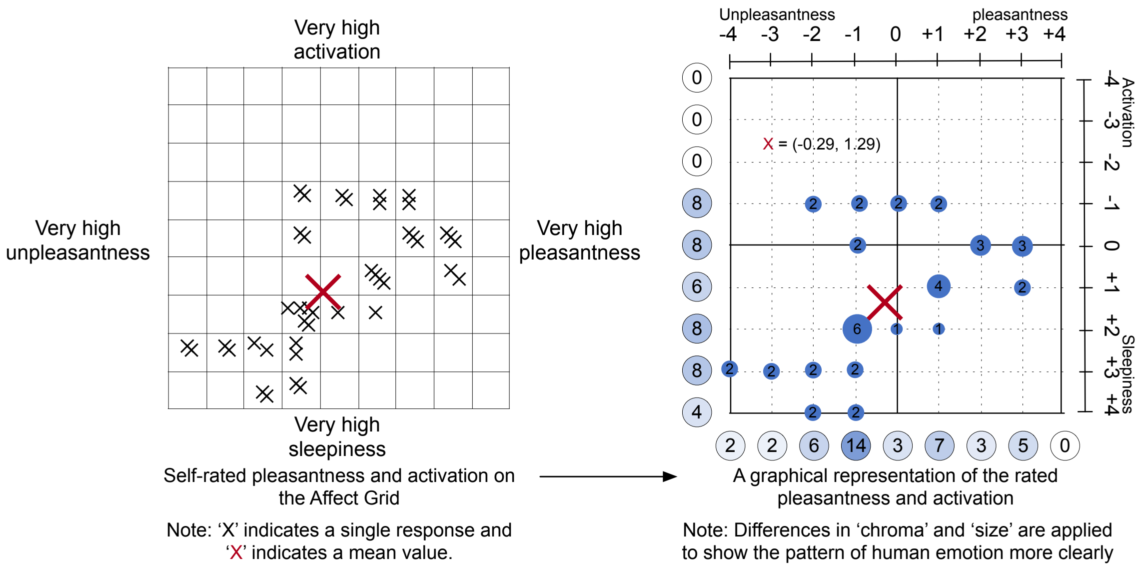


Figure 6.33. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under miscellaneous setting 2.

Miscellaneous setting 3

Figure 6.34 shows the result of perceived pleasantness/unpleasantness and activation/sleepiness under miscellaneous setting 3. The mean value of perceived emotion under this setting is similar to the one from M2 but their pattern seems slightly different. Considering that M1 and M3 settings both used a high CCT lamps (6000Kish), an increase or a decrease of light level can lead to an increase or decrease of subjective activation-sleepiness.

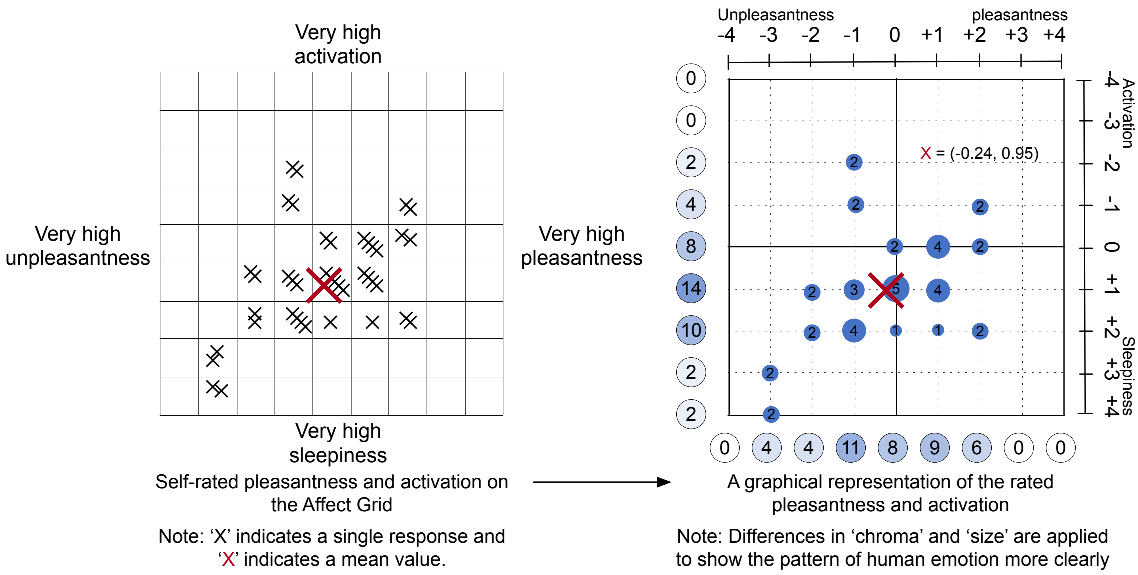


Figure 6.34. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under miscellaneous setting 3.

Miscellaneous setting 4

Figure 6.35 illustrates perceived levels of pleasantness/unpleasantness and activation/sleepiness under miscellaneous setting 4. As expected, almost all of the participants (40 out of 42) responded that they felt strong responses (greater than or equals to 2) of sleepiness under this setting. No participant reported a degree of activation. The mean value of perceived emotion also shows that the setting created strong responses on sleepiness. Although there were 10 respondents who described their feelings as pleasant, twice as many participants reported a degree of unpleasantness.

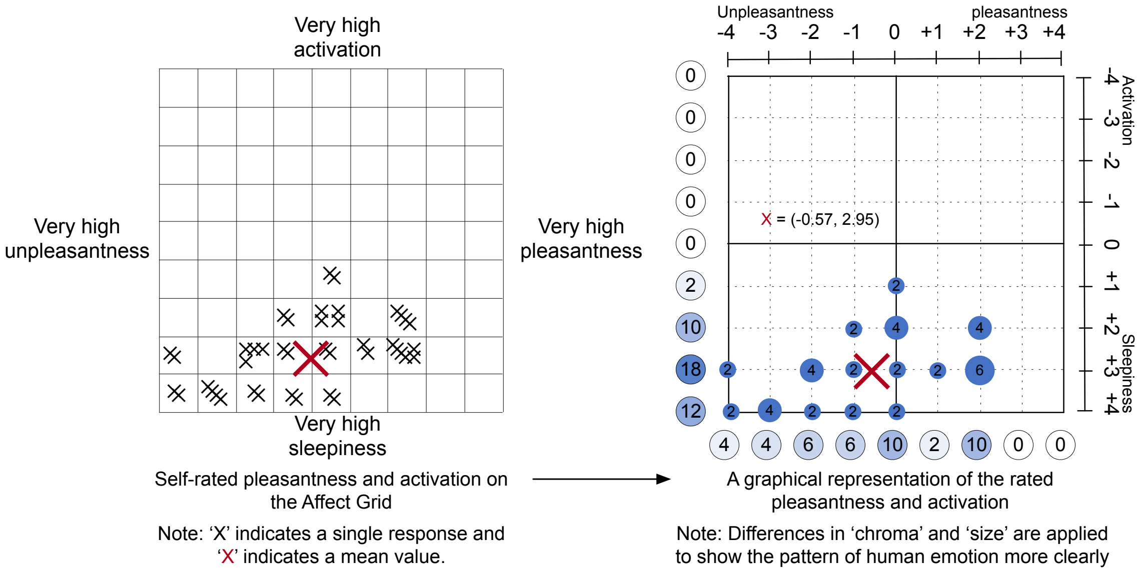


Figure 6.35. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under miscellaneous setting 4.

<u>Miscellaneous setting 5</u>

Self-rated pleasantness and activation levels under miscellaneous setting 5 is shown in Figure 6.36. The result immediately gives an impression that there were many responses on unpleasant-related feelings under this setting. The mean value of perceived emotion also clearly indicate that generally unpleasant feelings were dominantly evoked by this setting.

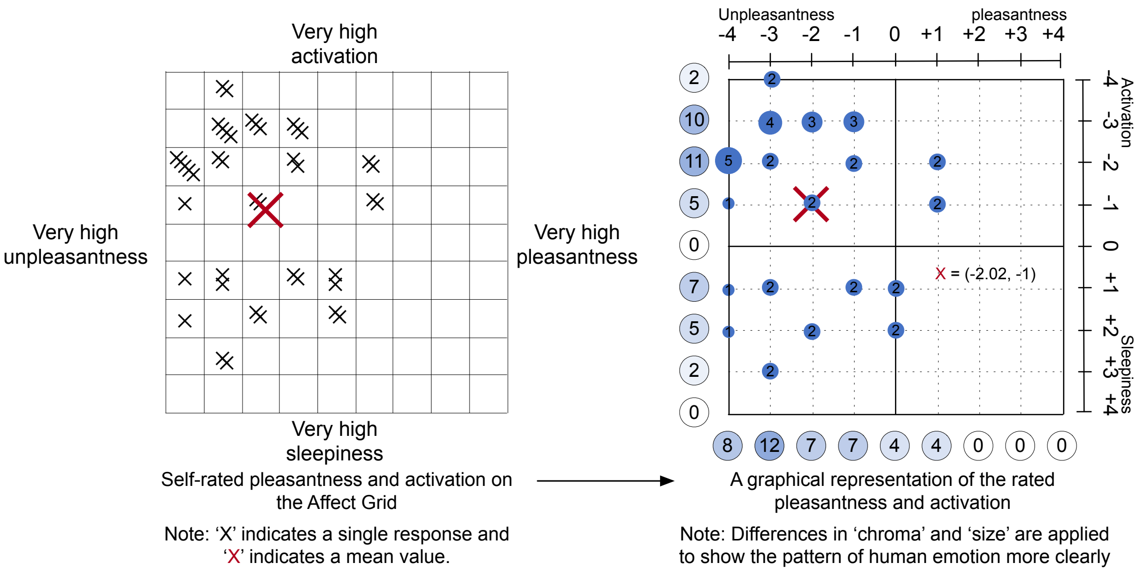


Figure 6.36. Self-rated pleasantness and activation on the Affect Grid (left figure) and its graphical representation (right figure) under miscellaneous setting 5.

6.2.4 Findings from perceived pleasantness and activation

This chapter has discussed the results of perceived pleasantness/unpleasantness and activation/sleepiness under fifteen light settings. To investigate whether lively and relaxing settings resulted in participants feeling the intended emotions of ‘lively (pleasing and with high activation)’ and ‘relaxing (pleasing and with high sleepiness)’, the study first calculated mean values of perceived pleasantness/unpleasantness and activation/sleepiness. Then, mean values of the fifteen settings were mapped on the two-dimensional emotion space, consisting of pleasantness and activation. Figure 6.37 shows the graphical presentation of the mean values.

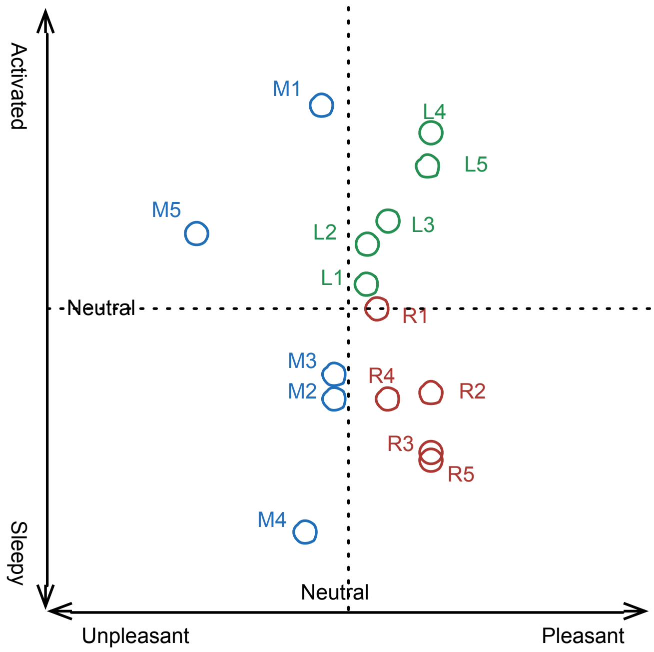


Figure 6.37. A graphical presentation of mean values of perceived pleasantness/unpleasantness and activation/sleepiness under fifteen light settings. Lively settings are coded in green, relaxing settings are coded in red and miscellaneous settings are coded in blue colour.

Based on the results of the mean values, it could be suggested that L4, L5 settings were most effective in creating ‘lively’ feelings and ‘relaxing’ emotion was most strongly found under R2, R3, and R5 settings. Figure 6.38 is also provided to illustrate the perceived pleasantness and activation under five lively, five relaxing settings, and miscellaneous settings in one figure.

First, what luminous elements were associated with L4, and L5 compared to other three lively settings? One clear design characteristic that L4 and L5 settings shared apart is that both settings included using a dynamic control that varied its colours from saturated blue to cyan. What about the relaxing settings? Are there any design characteristics that distinguished R1, R4 from R2, R3, and R5. Interestingly, both R1 and R4 used a dynamic control system that varied their colour properties whereas R2, R3, and R5 provided non-dynamic luminous conditions. Although there are only ten cases, it suggests that using a dynamic lighting setting has a potential to explore human emotion of 'lively' if appropriately used, whereas the same technique does not seem to be very effective in exploring human emotion of 'relaxing'. Human emotion of 'relaxing', according to the results in this study, seems to be more related with non-dynamic, generally warm colour appearance (see Figure 6.6 to Figure 6.10) of a space. The result of M5 setting clearly suggest that if a dynamic light setting is applied without a careful consideration, it could lead to a high level of unpleasant emotion.

Further to these findings, were any of lighting elements associated with human emotion of 'activation'? The results on M1, M2, M3, and M4 could be used to answer this question. As discussed in Chapter 6.2.3, there seems a clear impact of a change of CCT from 6500K (M1) to 2000K (M2) on human emotion of activation. The similar result was also noticed between M3 (6000K) to M4 (2000K). Based on this result, this study can argue that human subjective feeling of 'activation-sleepiness' can be explored through changing a CCT from very high one to very low value. According to the result in Figure 6.37, there seems to be no design or lighting elements that can directly explore human emotion of 'pleasantness'. If the study compares the result (Figure 6.37) with the hypothesized emotional responses (Figure 4.26), it can confidently claim that our hypothesized emotional responses were reasonably matched and confirmed by the controlled experiment.

Could the study further extend its finding by adopting the concept of lighting quality suggested by Boyce (2013a)? If his concept of good, bad and indifferent quality of lighting is applied, it can be argued that L4, L5, R2, R3, and R5 settings are classified as good quality as they were more effective in creating a feeling either 'lively' or 'relaxing' than others. However, such application is purely conceptual and does not have any empirical data to support the idea. The author, here, is just suggesting an interesting topic to think about.

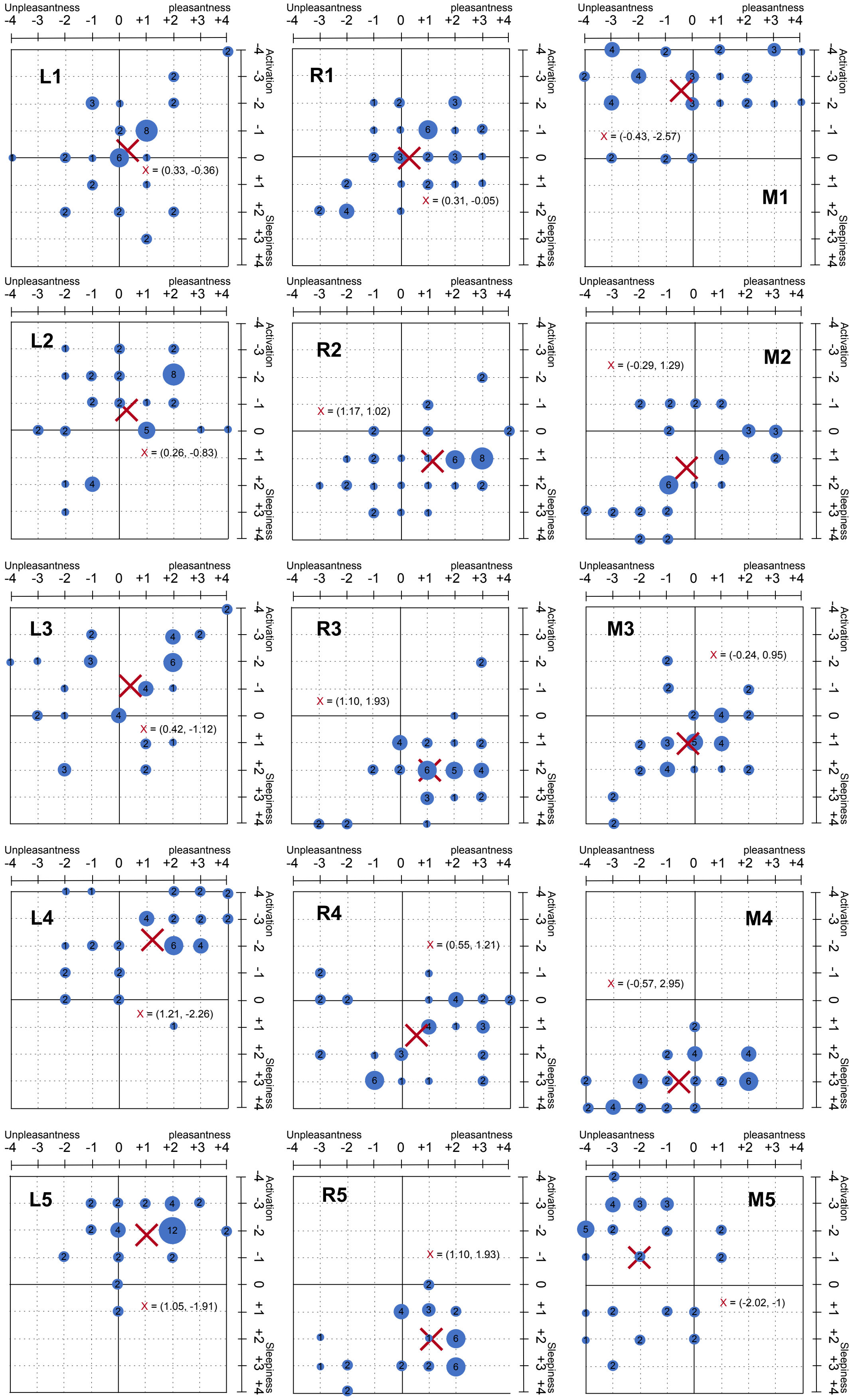


Figure 6.38. Perceived pleasantness and activation under the fifteen light settings

After looking at the above result, the results of the emotion responses to the various light settings seem to suggest that there are certain factors which are perceived as 'activation', 'lively, and 'relaxing'. However, it is also shown that the results of responses show a wide range, which might be due to the use of the uneven Likert scaling of responses. It can be claimed that if this study provided an even number of categories for perceived pleasantness and activation, the result might have avoided a potential tendency towards 'being neutral'.

In order to investigate whether such effect (or tendency) has been unintended caused in this study, an in-depth analysis was conducted and the result is explained in this section. Let's hypothesize that this study used an 8-point rating scale (even number) of 'pleasantness (1=completely unpleasant, to 8=completely pleasant)' and 'activation (1=completely activated to 8=completely sleepy)', instead of using a 9-point rating scale. Let's further hypothesize that the study provided an opt-out category for neutral respondents, which means adding a 'No option' or 'N/A option'.

An in-detail numbers of responses on each setting is well-described on Figure 6.22 to Figure 6.36 (and Figure 6.38) and Table 6.1 shows a comparison of the mean values of pleasantness and activation between using a 9-point scale and an 8-point scale under the fifteen light settings.

As shown in Table 6.2, mean perceived pleasantness value under L1, for example, was 5.33 (5=neutral) and the value would transform to be 4.8 (5=slightly pleasant) when a hypothetical 8-point rating scale was applied. Omitting neutral answers biases the data to be more in favour of 'being pleasant', when in, our sample in this study was much closer to being neutral on pleasantness. Evidently, this difference in scoring could completely change the outlook of this study's result. Therefore, the result on this analysis suggests that using an uneven number of Likert scaling in this study has an impact on the results, particularly on L1, L2, L3 and R1 settings, which participants averagely reported a feeling of close to being neutral in pleasantness.

However, then, should have this study used an even number of Likert scaling to measure human pleasantness and activation? The most important question here is would it be reasonable to force respondents to answer a question on either 'pleasant' or 'unpleasant'? Clearly, all the relevant literature in emotion studies (discussed in Chapter 2) seems to be against on this idea, which is why all of the well-established emotion scales use a 9-rating point. Therefore, this study concludes that although using a 9-rating point scale on human emotion could result in a situation where many participants rate their feelings being neutral, these results represents their true opinions on their feelings. Further, as shown in Table 6.2, some settings such as L4, L5, R3, M4, and M5 which resulted in relatively strong responses in pleasantness and activation, changing the rating scale does seem to influence their results. Participants' feelings under L4 and L5, for example, were highly pleasantness and highly activation regardless the difference in the scores of the rating scale, which supplement the argument of this study that using a 9-rating scale of human emotion is an effective tool to represent and measure an impact of lighting on human emotion.

Table 6.2. A comparison of the mean values of pleasantness and activation between using a 9-rating point scale and an 8-rating point scale (fifteen light settings)

	9-point rating scale*		8-point rating scale**	
	Pleasantness	Activation	Pleasantness	Activation
L1	1=1 response(s) 2=0 response(s) 3=4 responses(s) 4=6 response(s) 5=11 response(s) 6=12 response(s) 7=6 response(s) 8=0 response(s) 9=2 response(s) Total:42 (Mean: 5.33)	1=2 response(s) 2=2 response(s) 3=6 responses(s) 4=10 response(s) 5=11 response(s) 6=3 response(s) 7=6 response(s) 8=2 response(s) 9=0 response(s) Total:42 (Mean: 4.64)	1=1 response(s) 2=0 response(s) 3=4 responses(s) 4=6 response(s) 5=12 response(s) 6=6 response(s) 7=0 response(s) 8=2 response(s) N/A=11 response(s) Total:31 (Mean: 4.8)	1=2 response(s) 2=2 response(s) 3=6 responses(s) 4=10 response(s) 5=3 response(s) 6=6 response(s) 7=2 response(s) 8=0 response(s) NA=11 response(s) Total:31 (Mean: 4.16)
L2	Total:42 (Mean: 5.26)	Total:42 (Mean: 4.16)	Total:36 (Mean: 4.75)	Total:31 (Mean: 3.67)
L3	Total:42 (Mean: 5.42)	Total:42 (Mean: 3.88)	Total:38 (Mean: 4.84)	Total:35 (Mean: 3.43)
L4	Total:42 (Mean: 6.21)	Total:42 (Mean: 2.73)	Total:36 (Mean: 5.66)	Total:38 (Mean: 2.47)
L5	Total:42 (Mean: 6.05)	Total:42 (Mean: 3.10)	Total:30 (Mean: 5.66)	Total:40 (Mean: 2.95)
R1	Total:42 (Mean: 5.31)	Total:42 (Mean: 4.95)	Total:34 (Mean: 4.76)	Total:31 (Mean: 4.48)
R2	Total:42 (Mean: 6.17)	Total:42 (Mean: 6.02)	Total:39 (Mean: 5.53)	Total:36 (Mean: 5.30)
R3	Total:42 (Mean: 6.10)	Total:42 (Mean: 6.93)	Total:36 (Mean: 5.44)	Total:41 (Mean: 6.02)
R4	Total:42 (Mean: 5.55)	Total:42 (Mean: 6.21)	Total:38 (Mean: 5)	Total:29 (Mean: 5.86)
R5	Total:42 (Mean: 6.10)	Total:42 (Mean: 6.93)	Total:36 (Mean: 5.44)	Total:38 (Mean: 6.13)
M1	Total:42 (Mean: 4.57)	Total:42 (Mean: 2.43)	Total:34 (Mean: 4.05)	Total:36 (Mean: 2)
M2	Total:42 (Mean: 4.71)	Total:42 (Mean: 6.28)	Total:39 (Mean: 4.31)	Total:34 (Mean: 5.82)
M3	Total:42 (Mean: 4.76)	Total:42 (Mean: 5.95)	Total:34 (Mean: 4.26)	Total:34 (Mean: 5.35)
M4	Total:42 (Mean: 4.43)	Total:42 (Mean: 7.95)	Total:32 (Mean: 3.88)	Total:42 (Mean: 6.95)
M5	Total:42 (Mean: 2.97)	Total:42 (Mean: 4)	Total:38 (Mean: 2.66)	Total:42 (Mean: 3.67)

*1='completely unpleasant or activated', 5='neutral', 9='completely pleasant or sleepy'
**1='completely unpleasant or activated', 8='completely pleasant and sleepy'.

The study also investigated of whether any of lighting characteristics recorded explain perceived pleasantness and activation. Figure 6.39 shows a graphical presentation of mean values of perceived pleasantness under fifteen settings. Four photometric characteristics of the settings are also provided on the right-hand side of the figure. As clearly seen in Figure 6.39, first, there is no clear trend of either increasing or decreasing in pleasantness. All that can be found from the graphical presentation is that there is large variability to responses on pleasantness.

	Unpleasantness -4	-3	-2	-1	0	+1	+2	+3	pleasantness +4	Mean	E_{task}	L_{av} (B40)	$L_{Max}:L_{Min}$	MRSE
L4	0	0	6	3	6	4	11	8	4	Mean: 1.21	416	34	5.6:1	78
R2	0	1	3	7	3	7	7	12	2	Mean: 1.17	333	63	3.9:1	106
R3	0	2	2	2	6	12	8	10	0	Mean: 1.10	312	14	16.7:1	47
R5	0	2	4	0	6	8	14	8	0	Mean: 1.10	285	15	25.7:1	29
L5	0	0	2	4	12	2	18	2	2	Mean: 1.05	697	61	4:1	146
R4	0	6	2	7	4	7	5	9	2	Mean: 0.55	389	29	3.9:1	72
L1	1	3	5	5	4	8	12	2	2	Mean: 0.43	760	22	16.2:1	74
L3	1	0	4	6	11	12	6	0	2	Mean: 0.33	1116	71	4.3:1	154
R1	0	2	6	5	8	10	7	4	0	Mean: 0.31	604	61	3.6:1	129
L2	0	2	6	8	6	6	12	1	1	Mean: 0.26	640	74	5:1	157
M3	0	4	4	11	8	9	6	0	0	Mean: -0.24	388	59	12:1	80
M2	2	2	6	14	3	7	3	5	0	Mean: -0.29	1312	81	8.6:1	196
M1	2	10	4	4	8	4	4	4	2	Mean: -0.43	1873	118	7.7:1	273
M4	4	4	6	6	10	2	10	0	0	Mean: -0.57	220	18	9.7:1	35
M5	8	12	7	7	4	4	0	0	0	Mean: -2.02	329	26	5.1:1	57

Figure 6.39. A graphical presentation of mean values of perceived pleasantness under fifteen settings. Four photometric characteristics of the settings were also provided on the right-hand side of the figure.

Clearly, neither of MRSE nor luminance related metric is associated with perceived pleasantness. Then, would there be any metric that can be associated with human emotion of 'activation'? In order to investigate this, another graphical presentation of mean values of perceived activation under fifteen settings is provided, as shown in Figure 6.40. Unlike the case of perceived pleasantness, it is clearly noticed that human emotion of activation has been effectively explored by the fifteen light settings. Similar to human perception of brightness (see Figure 6.16), a general trend is noticed. However, there are again some irregular responses that cannot be explained by the measured metrics. For example, how has L4 and L5 settings caused such high level of activation is difficult to answer.

	Sleepiness								Activation					
	4	3	2	1	0	-1	-2	-3	-4	**Mean**	**E_{task}**	**L_{av} (B40)**	**L_{Max} : L_{Min}**	**MRSE**
M1	0	0	0	0	6	0	12	12	12	Mean: -2.57	1873	118	8.6:1	273
L4	0	0	0	1	4	4	15	10	8	Mean: -2.26	416	34	5.6:1	78
L5	0	0	0	2	2	6	20	12	0	Mean: -1.91	697	61	4:1	146
L3	0	1	5	0	11	7	13	5	0	Mean: -1.12	1116	71	4.3:1	74
M5	0	2	5	7	0	5	11	10	2	Mean: -1	329	26	5.1:1	57
L2	0	1	5	0	11	7	13	5	0	Mean: -0.83	640	74	5:1	157
L1	2	2	6	10	11	3	6	2	0	Mean: -0.36	760	22	16.2:1	74
R1	0	0	7	7	11	11	6	0	0	Mean: -0.05	604	61	3.6:1	129
M3	2	2	10	14	8	4	2	0	0	Mean: 0.95	388	59	12:1	80
R2	0	4	9	19	6	2	2	0	0	Mean: 1.02	333	63	3.9:1	78
R4	0	10	8	8	13	3	0	0	0	Mean: 1.21	389	29	3.9:1	72
M2	4	8	8	6	8	8	0	0	0	Mean: 1.29	1312	81	8.6:1	196
R3	5	6	19	9	1	0	2	0	0	Mean: 1.93	312	14	16.7:1	47
R5	2	14	9	13	4	0	0	0	0	Mean: 1.93	285	15	25.7:1	29
M4	12	18	10	2	0	0	0	0	0	Mean: 2.95	220	18	9.7:1	35

Figure 6.40. A graphical presentation of mean values of perceived activation under fifteen settings. Four photometric characteristics of the settings were also provided on the right-hand side of the figure.

In summary, perceived appearance under the fifteen light settings are first explained in this chapter. The result shows that a wide range of human perception of a space such as ‘uninteresting’ to ‘very interesting’ and ‘very dim’ to ‘very bright’ has been stimulated by the fifteen light settings. Then, several design indicators have been tested whether their hypothesized assumptions were matched or not. Human emotion of ‘pleasantness’ and ‘activation’ were also explored by the fifteen light settings and some design elements that appears to be associated with human emotion of ‘lively’ and ‘relaxing’ were identified.

Chapter 7

Result and findings from the experiment: Part II

This chapter continues to report the result and the findings from the controlled experiment. This chapter first illustrates the results of perceived emotions under fifteen light setting which were obtained using the twenty-four emotion descriptors. Then, the results are compared with the perceived pleasantness and activation, which was discussed in previous chapter. Then, the chapter concludes the findings of an impact of lighting on human emotion.

7.1 Emotion using the emotion-descriptors

As explained in Chapter 3, twenty-four emotion descriptors, which were derived from the circumplex model of affect were used to measure participants' emotional experience under each light setting. As a reminder of the descriptors, Figure 7.1 represents the twenty-four emotion descriptors, which was originally shown in Figure 3.9.

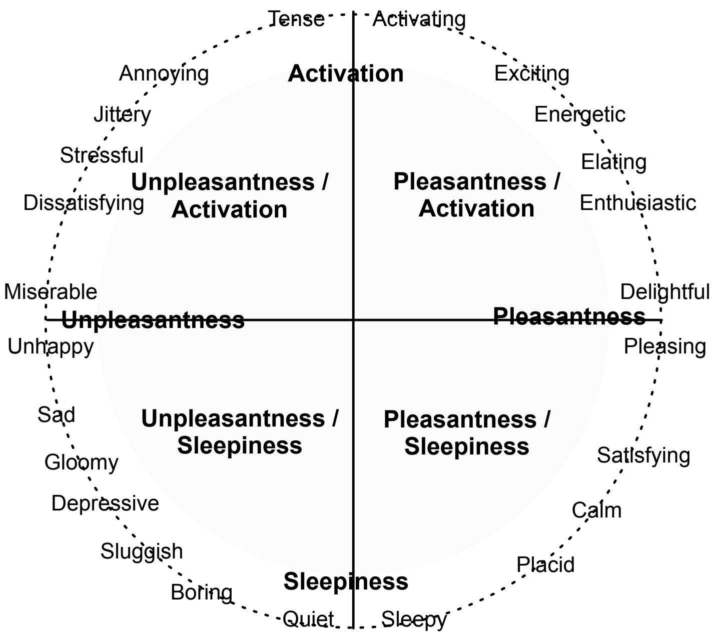


Figure 7.1. Twenty-four emotion descriptors, derived from the circumplex model of affect. **Bold** letters indicate four theoretical zones defined by two dimensions of human emotion.

7.1.1 Lively settings

<u>Lively setting 1</u>

Participants' emotional experiences under lively setting 1, measured by the descriptors is shown in Figure 7.2. For a clear explanation of the result, the circumplex model with the descriptors is also presented on the right-hand side. The result indicates that the descriptors such as 'pleasing', 'delightful' were most frequently used under L1 setting, which were followed by 'activating' and 'calm'. Some participants also used the words such as 'enthusiastic' and 'exciting' to describe their feelings during the experiment. Although some descriptors on unpleasantness/sleepiness zone were noticed, the overall emotional experience was focused on pleasantness/activation and pleasantness/sleepiness zones.

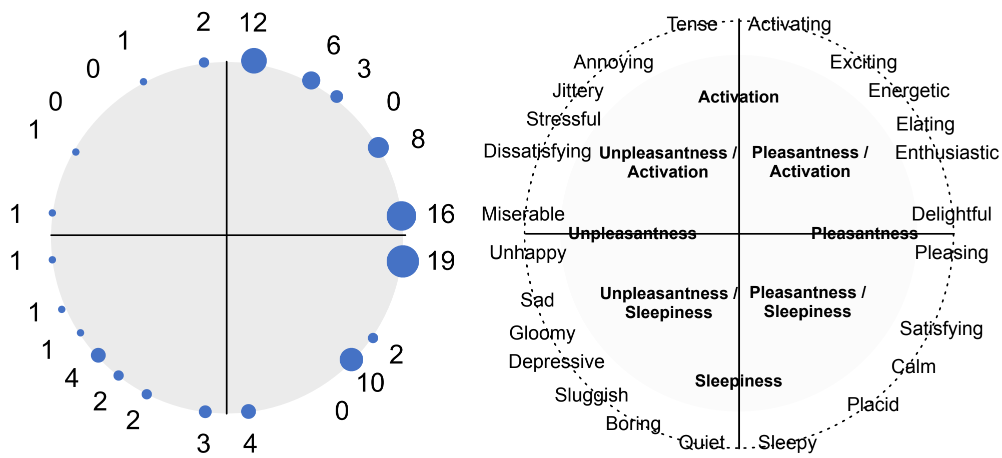


Figure 7.2. Perceived emotions under L1 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

<u>Lively setting 2</u>

Figure 7.3 shows perceived emotion under lively setting 2 by the emotion descriptors. It is shown that the descriptors such as 'activating', 'satisfying', and 'pleasing' were most frequently used to describe the respondents' feelings during the experiment. It is also noticed that some participants expressed their feelings as 'calm', 'energetic, 'enthusiastic' and 'boring'. Only a few participants responded that the environment was 'delightful', 'sleepy' and 'tense'. Compared to L1 setting, participants reported more pleasantness/sleepiness, and activation but less pleasantness.

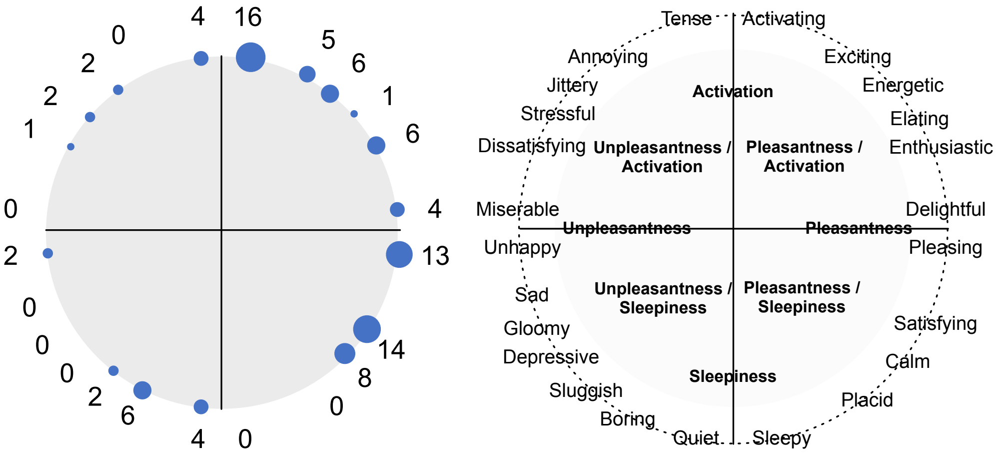


Figure 7.3. Perceived emotions under L2 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

Lively setting 3

The result of reported emotion descriptors under lively setting 3 is shown in Figure 7.4. It is found that the users' feelings under this setting were described as 'tense', 'activating', and 'calm' most frequently. Although some participants described their positive feelings such as 'energetic', and 'pleasing' under this setting, a similar number of the participants also reported negative feelings such as 'depressive' and 'stressful'. Overall, the results in Figure 7.4 gives an impression that participants' emotional responses under L3 were evenly distributed over the four quadrants.

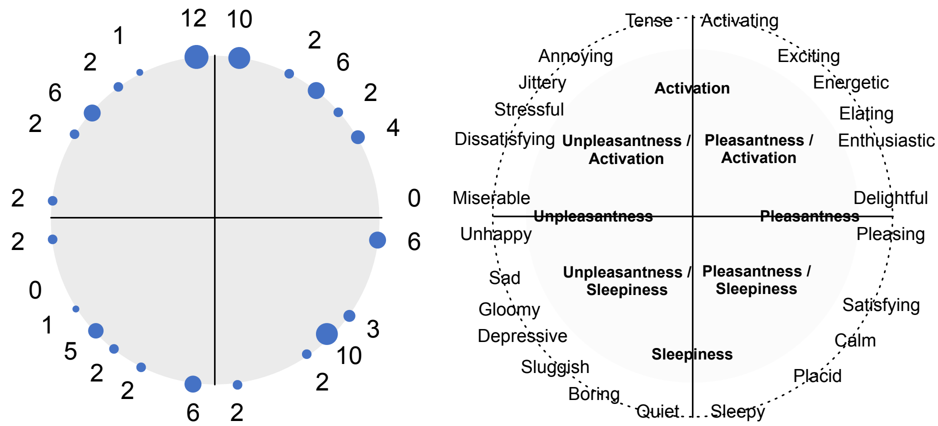


Figure 7.4. Perceived emotions under L3 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

Lively setting 4

Figure 7.5 shows the result of perceived emotion on the circumplex model of affect under L4 setting. The result shows that the setting was frequently perceived as ‘activating’, ‘energetic’, ‘enthusiastic’, and ‘pleasing’. Participants also described their feelings as ‘tense’, ‘satisfying’, ‘exciting’, and ‘calm’. Overall, it could be explained that L4 stimulated human activation, pleasant activation, pleasantness, and pleasant sleepiness.

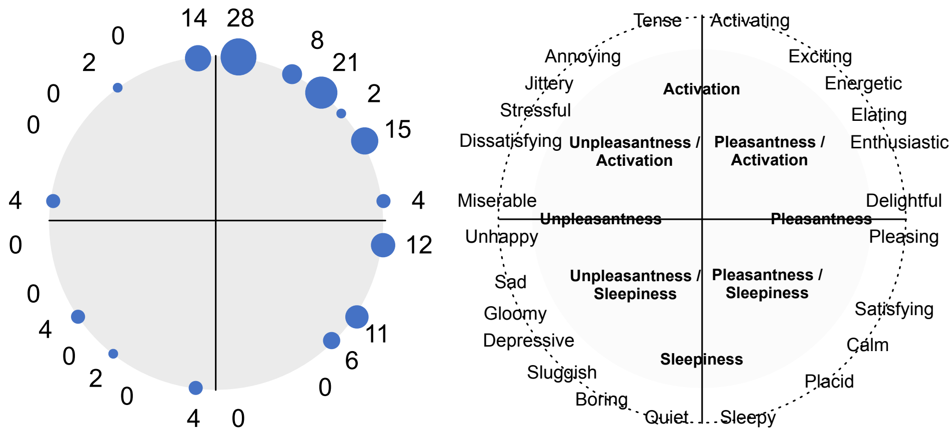


Figure 7.5. Perceived emotions under L4 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

Lively setting 5

Figure 7.6 illustrates perceived emotion of participants under L5 setting on the circumplex model of affect. The result shows that participants described their feelings as ‘activating’, and ‘energetic’ most frequently, which was followed by ‘enthusiastic’, ‘satisfying’, ‘delightful’, and ‘pleasing’. Overall, it could be seen that participants reported similar emotion compared to the experience under L4.

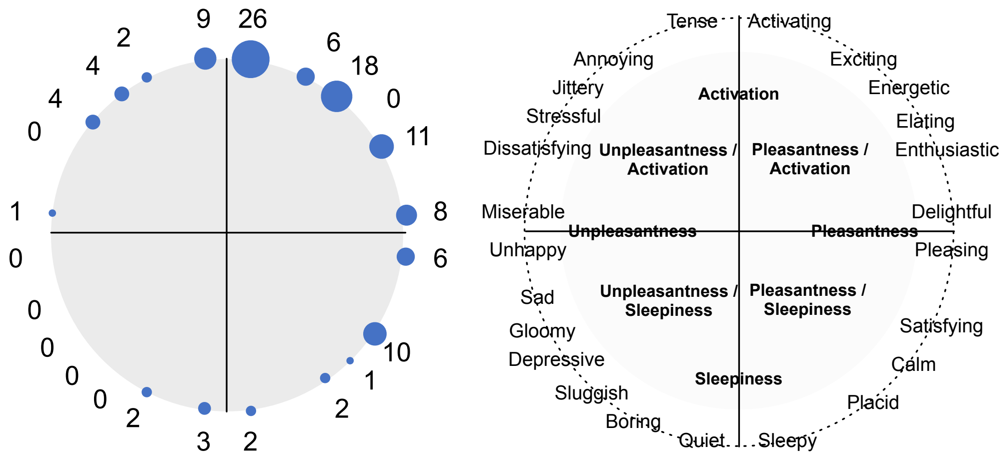


Figure 7.6. Perceived emotions under L5 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

7.1.2 Relaxing settings

Relaxing setting 1

Participants' feelings measured by the emotion descriptors under relaxing setting 1 is illustrated in Figure 7.7. The result shows that perceived emotions under this setting were most frequently described as 'calm', 'delightful', 'satisfying' and 'pleasing'. It is also noticed that some emotions on pleasantness/activation and sleepiness zone were also stimulated. In general, it could be described that participants' feelings of this setting was mainly consisted of pleasant sleepiness, pleasantness and pleasant activation. Although a few negative descriptors such as 'sluggish', 'miserable', and 'unhappy' were used, their frequencies were relatively much smaller than the uses of positive emotion descriptors.

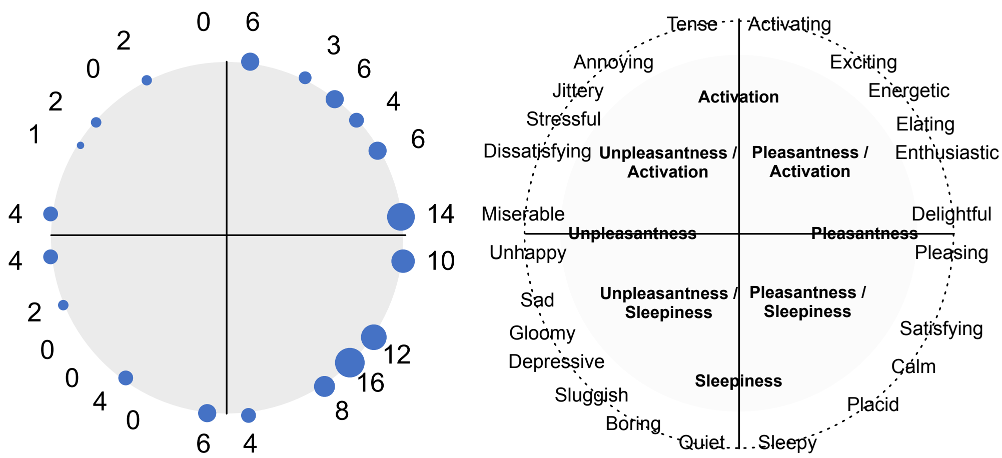


Figure 7.7. Perceived emotions under R1 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

Relaxing setting 2

Figure 7.8 shows perceived emotions of participants under R2 setting on the circumplex model of affect. The result suggests that feelings under this setting were mostly described as 'calm', 'pleasing', and 'delightful', which were followed by 'quiet', and 'satisfying'. Unlike R1 setting, almost no stimulation on pleasantness/activation zone is found. In general, the perceived emotion under R2 setting was consisted of pleasantness, pleasant sleepiness, sleepiness and slight unpleasant sleepiness.

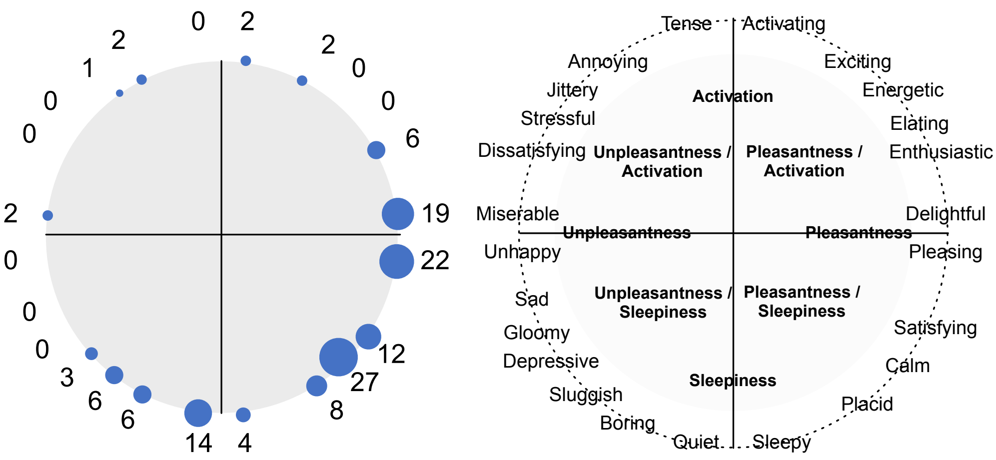


Figure 7.8. Perceived emotions under R2 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

<u>Relaxing setting 3</u>

Figure 7.9 illustrates the perceived feelings of the respondents under R3 setting on the circumplex model of affect. First, it is noticed that the setting did not stimulate any emotion on unpleasantness/activation, activation, and pleasantness/activation zones. ‘Calm’, ‘quiet’, and ‘sleepy’ were the three most frequently used adjectives to describe participants’ feeling. Some also reported feelings of ‘pleasing’ and ‘satisfying’, ‘placid’ and ‘boring’. Overall, the setting stimulated sleepiness of human emotion strongly along with pleasant sleepiness and pleasantness.

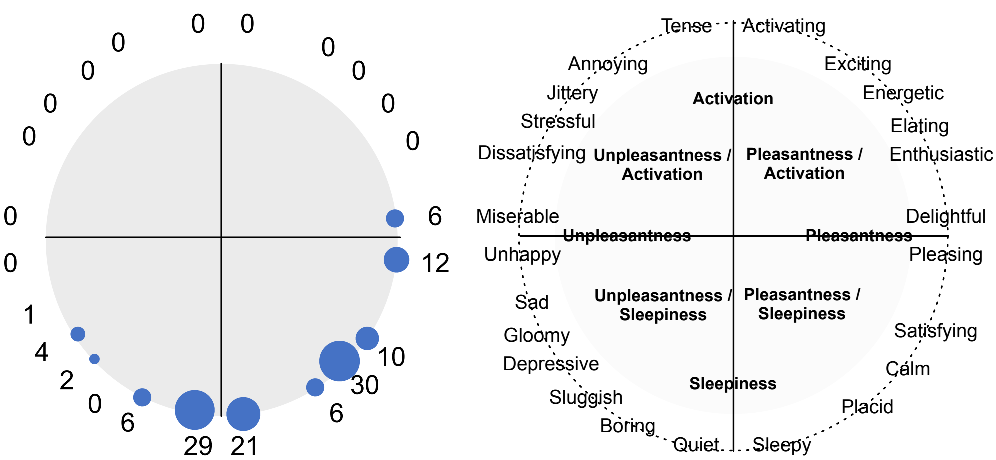


Figure 7.9. Perceived emotions under R3 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

<u>Relaxing setting 4</u>

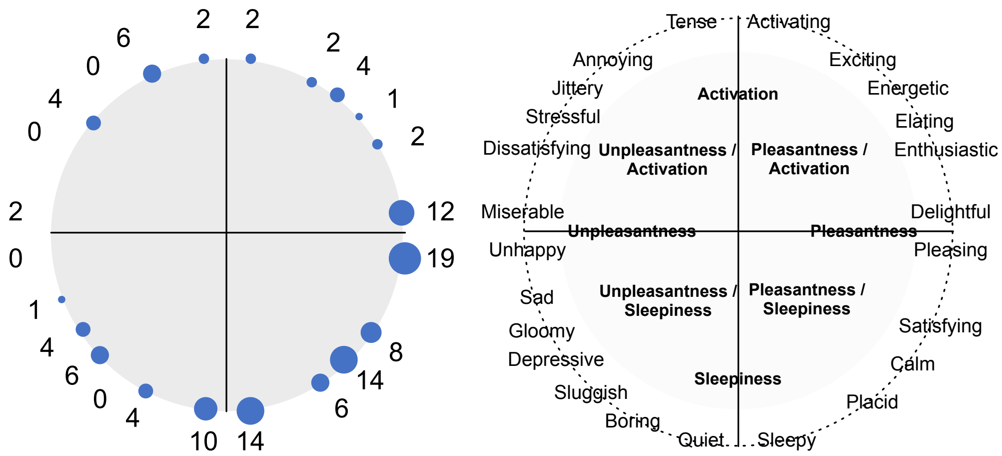


Figure 7.10. Perceived emotions under R4 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

Participants' perceived feelings under R4 setting on the circumplex model of affect is shown in Figure 7.10. The result shows that the setting stimulated human emotion in the lower hemisphere widely. The adjectives such as 'pleasing', 'sleepy', 'calm', 'delightful' and 'quiet' were frequently used to describe the respondents' feelings. Some negative feelings of unpleasant sleepiness and unpleasant activation were also noticed.

<u>Relaxing setting 5</u>

Figure 7.11 shows perceived feelings of participants under R5 setting on the circumplex model of affect. Like the feelings under R3, no participants reported feelings of upper hemisphere of the circumplex. The result shows that feelings were mostly described as 'quiet', and 'calm'. Significant number of participants also expressed the feelings of 'sleepy', and 'pleasing'. It is also noticed that minority of participants felt negative feelings such as 'gloomy', 'sluggish', and 'boring'. In general, the setting clearly stimulated human emotion of sleepiness, and pleasant sleepiness along with pleasantness. Interestingly, apart from a frequent feeling of 'calm', almost no stimulation on pleasantness/sleepiness was noticed.

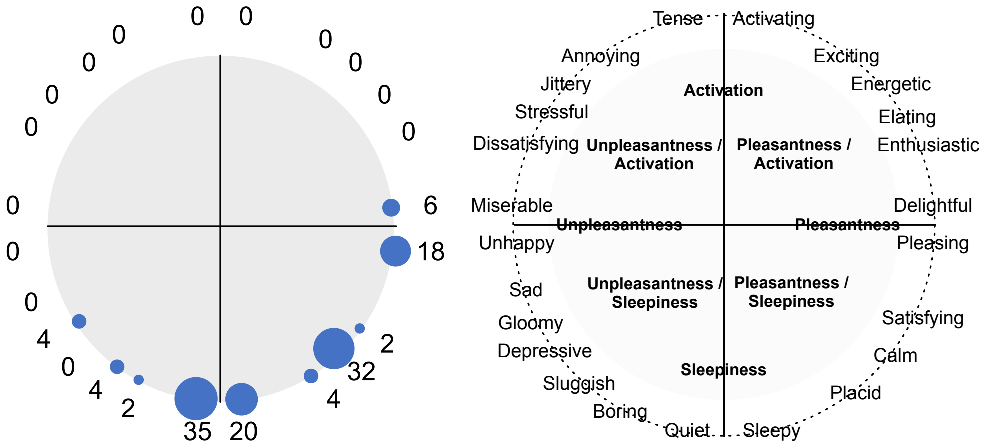


Figure 7.11. Perceived emotions under R5 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

7.1.3 Miscellaneous settings

<u>Miscellaneous setting 1</u>

Participants' feelings under M1 setting is shown as the circumplex model of affect in Figure 7.12. The result indicates that M1 mostly stimulated upper hemisphere of the circumplex emotion. The most frequently reported feelings were 'activating', 'energetic', 'enthusiastic', and 'tense'. Although pleasantness/activation of human emotion was clearly stimulated, it is noticed that the setting created unpleasant activating environments, which were described as 'annoying', and 'stressful'. Unlike most of lively and relaxing setting, only few participants described an emotion of pleasantness and pleasantness/sleepiness under this luminous environment. Overall, it could be described that M1 setting created very active set of responses to the participants.

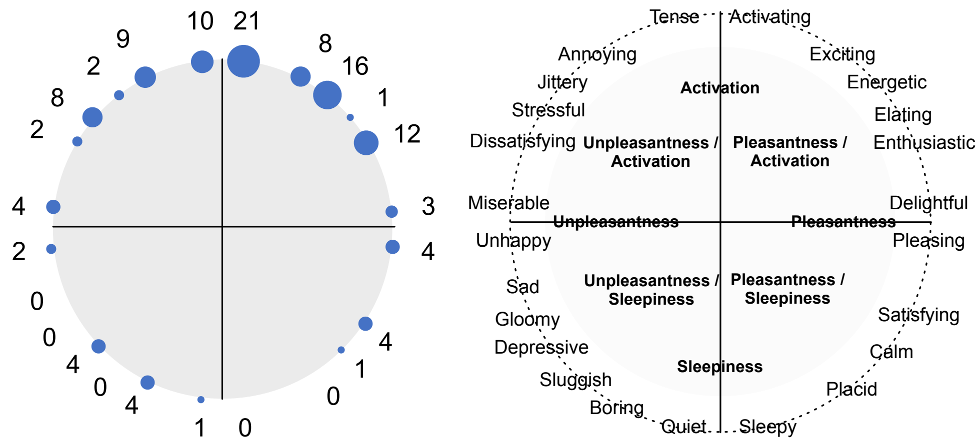


Figure 7.12. Perceived emotions under M1 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

<u>Miscellaneous setting 2</u>

Figure 7.13 shows participants' perceived emotion under M2 setting on the circumplex model of affect. One clear characteristic of the result is a wide stimulation in both upper and lower part of the emotion hemisphere. Based on the result, it would be difficult to argue that M2 setting stimulated certain part of human emotion. The result indicates that our emotional responses from a luminous environment could widely spread into both positive, and negative feelings or both activating and sleepy. This is a particularly interesting result as it could suggest that assessing human emotion from lighting by intensities on two dimensions (or even three-dimensions) would not be very effective under a case like this. A further investigation in this matter is discussed in the next section. The result also shows a strong influence of colour appearance (from CCT of 6,500K to CCT of 2,000K) on human emotion, especially compared to the result under M1 setting.

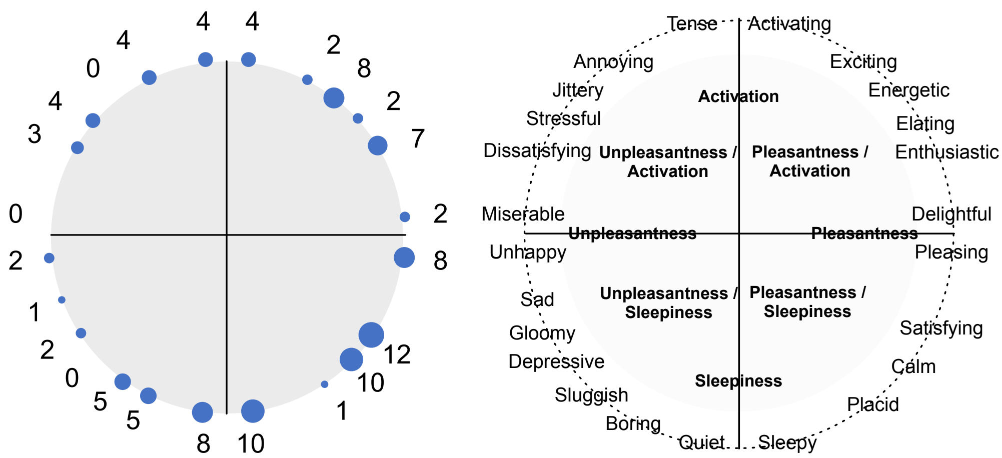


Figure 7.13. Perceived emotions under M2 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

<u>Miscellaneous setting 3</u>

Participants' emotional responses under M3 setting is shown as the circumplex model of affect in Figure 7.14. The result indicates that the feelings under M3 shares a similar characteristic to the feelings under R2, R3, and R5, which was almost no simulation on upper part of emotion hemisphere. However, unlike these settings, participants reported much less frequent of pleasantness and much more frequent of unpleasant sleepiness under M3 setting. 'Quiet' and 'Calm' were two most frequently reported feelings, which were followed by 'gloomy', 'depressive', 'satisfying', and 'sad'. Overall, based on the result, it could be said that M3 setting created strong responses of sleepiness from the participants.

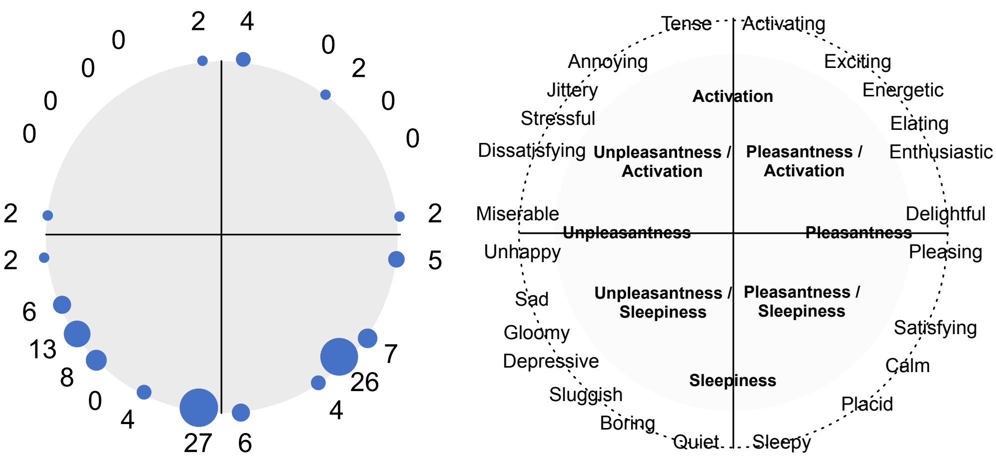


Figure 7.14. Perceived emotions under M3 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

<u>Miscellaneous setting 4</u>

Figure 7.15 shows participants' self-reported feelings on the circumplex model of affect under M4 setting. The result shows a distinctly different pattern of emotion compared to all the above settings. In general, the left hemisphere of the circumplex emotion was stimulated under this luminous environment along with pleasantness/sleepiness zone. The most frequently reported feeling was 'sleepy', which was followed by 'quiet', 'calm', 'gloomy', 'depressive', and 'dissatisfying'. Interestingly, it is noticed that there were several responses in both quadrants of 'pleasantness/sleepiness' and 'unpleasantness/activation', which is an opposite end of the same dimension. Overall, it could be described the setting created strong responses of unpleasant sleepiness from the participants.

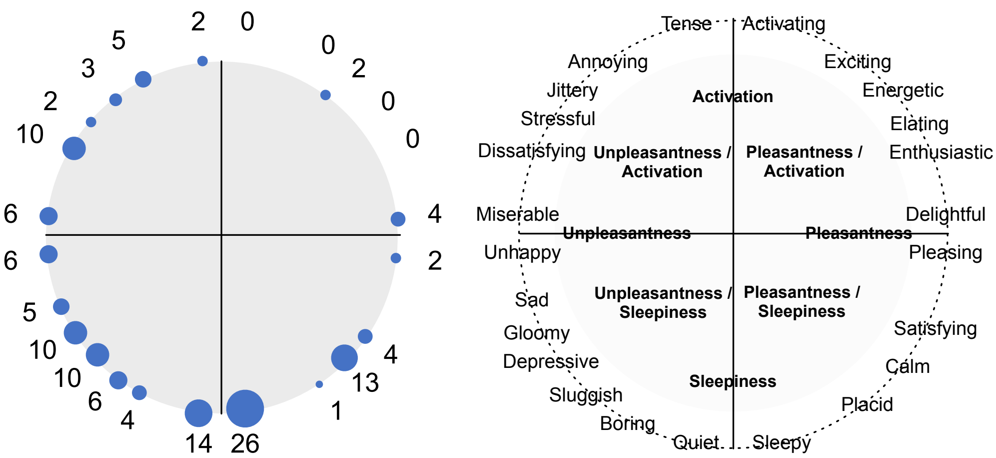


Figure 7.15. Perceived emotions under M4 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

<u>Miscellaneous setting 5</u>

Participants self-reported feelings under M5 setting was also analysed and the result is shown in Figure 7.16. The feelings were mostly described as ‘exciting’, ‘annoying’, ‘delightful’ and ‘activating’. Since the light setting of M5 was intended to create the most exciting visual scene, the result seems logical in the context. It is also noticed that pleasantness/activation and unpleasantness/activation were frequently reported under this setting whereas human emotion of activation was relatively less frequently reported. There was almost no participant who described a feeling of pleasant sleepiness and sleepiness under M5. One thing to notice is that only M5 among the fifteen light settings, resulted in much more frequent self-rated feeling of ‘delightful’ than a feeling of ‘pleasing’, which was almost never described.

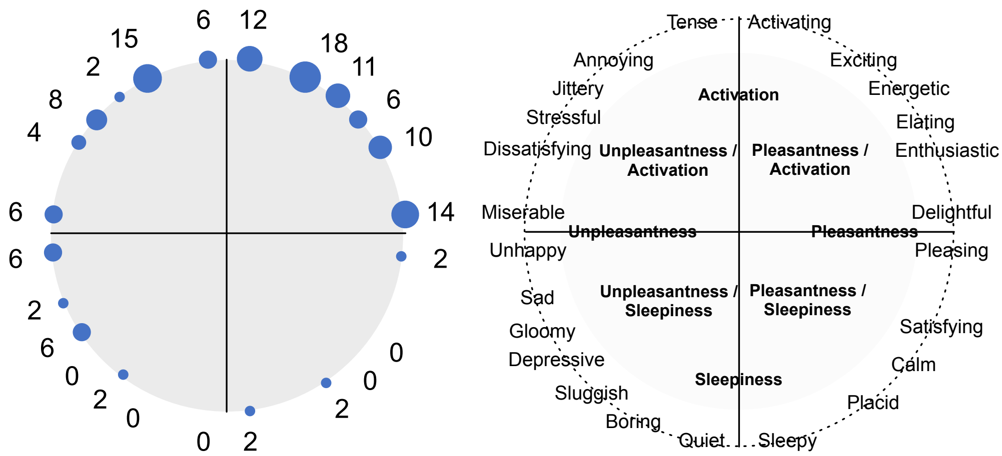


Figure 7.16. Perceived emotions under M5 on the circumplex model of affect. The numbers in the outer circle indicate measured frequencies of descriptors and the circle in the inner circle are proportional to the frequency numbers (left-hand side figure). Right-hand side figure shows the emotion descriptors on four quadrants of the circumplex.

7.1.4 Findings from the circumplex model of affect

Participants’ self-reported emotion (or feeling) with the emotion descriptors under fifteen light setting were discussed in the previous section. In this section, a further analysis of the fifteen emotion responses was conducted and explained. Figure 7.18 shows all the results of perceived emotions under fifteen light settings.

One finding from the perceived emotions is that except for M1 and M5 setting, all the settings stimulated human emotion of pleasant sleepiness. More specifically, all the lively settings, which aimed to evoke pleasant activation to its occupants, stimulated human emotion of activation, pleasant activation, pleasantness and pleasant sleepiness whereas under R3 and R5 settings, participants did not report any of feeling of ‘exciting’, ‘energetic’, ‘elating’, and ‘enthusiastic’. These results could be interpreted in several ways. It could be argued that lighting easily evokes a feeling of pleasant sleepiness regardless luminous conditions. In fact, two light settings, M1 and M5 which did not stimulate the human emotion of pleasant sleepiness, were created as extreme luminous conditions. M1 provided the highest level of lights, much exceeding the recommended values, with high CCT lamps (6,500K) and M5 setting used a high variety of coloured lights, which would not be considered as appropriate for workspace environment.

If human emotion of pleasant sleepiness is easily stimulated by most of lighting conditions, current uses of emotion assessment based on two dimensions needs to be revised when applied to lighting studies. The results under L3 and M4, for example, shows that human emotion of pleasant sleepiness and unpleasant activation were both stimulated by lighting, which theoretically lies on opposite ends of a single dimension. In terms of a dimension of activation/sleepiness, there was no result that shows both frequently activating but also frequently sleepy. Regarding a dimension of pleasantness/unpleasantness, only one setting, M5, stimulated in both frequent pleasantness and frequent unpleasantness. However, in a real environment, it would be highly unlikely to find a workspace with an M5 type of luminous condition.

Another thing to notice from the below results is a relationship between perceived feeling of ‘delightful’ and luminous conditions. As can be seen from the result, unlike a feeling of ‘pleasing’, which also lies on a similar dimension of pleasantness, only a few settings out of the fifteen settings stimulated human emotion of ‘delightful’ frequently, which were R2 (19 times), L1 (16 times), R1 (14 times), M5 (14 times), and R4 (12 times). Among these five settings, L1, R1, and M5 have a common design characteristic of involving several coloured lights within the field of view. However, it does not explain the result of R2, which did not include any of non-white light sources. The study assumes that having a variety of coloured lights within the field of view (including the non-task area) could be one way of evoking ‘delightful’ emotion but there are still unknown factors in this matter.

Lastly, since perceived emotions in this section were assessed by self-reporting of the descriptors, a total number of reported feelings varied among the settings. Figure 7.17 shows a bar chart diagram of total numbers of self-reported feelings under fifteen light settings. As can be seen from the chart, participants tended to report greater numbers of feelings under relaxing settings than lively settings except for L4 and L5. Having a greater number of feelings should not be interpreted as a good sign of emotion as M3, M4, and M5 also received high numbers of feelings. All that can be assumed is that human emotion tends to be more sensitive (tends to create more responses) to warm colour appearance compared to neutral colour appearance.

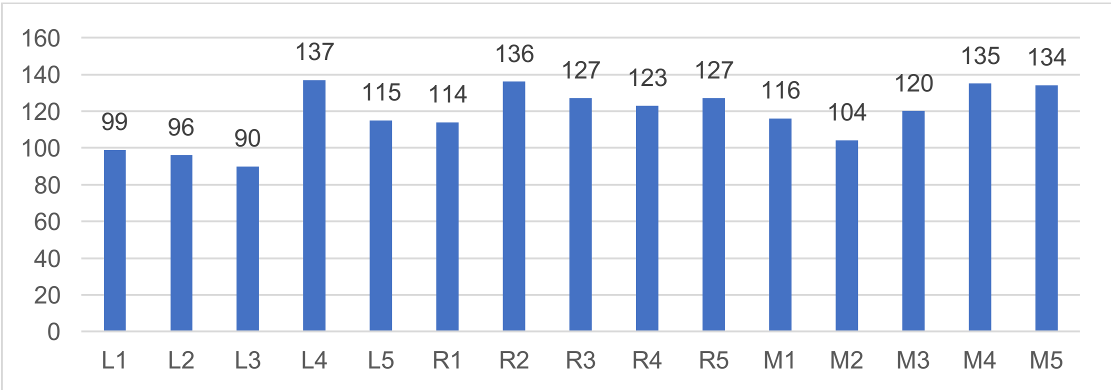


Figure 7.17. Total numbers of self-reported feelings under fifteen light settings

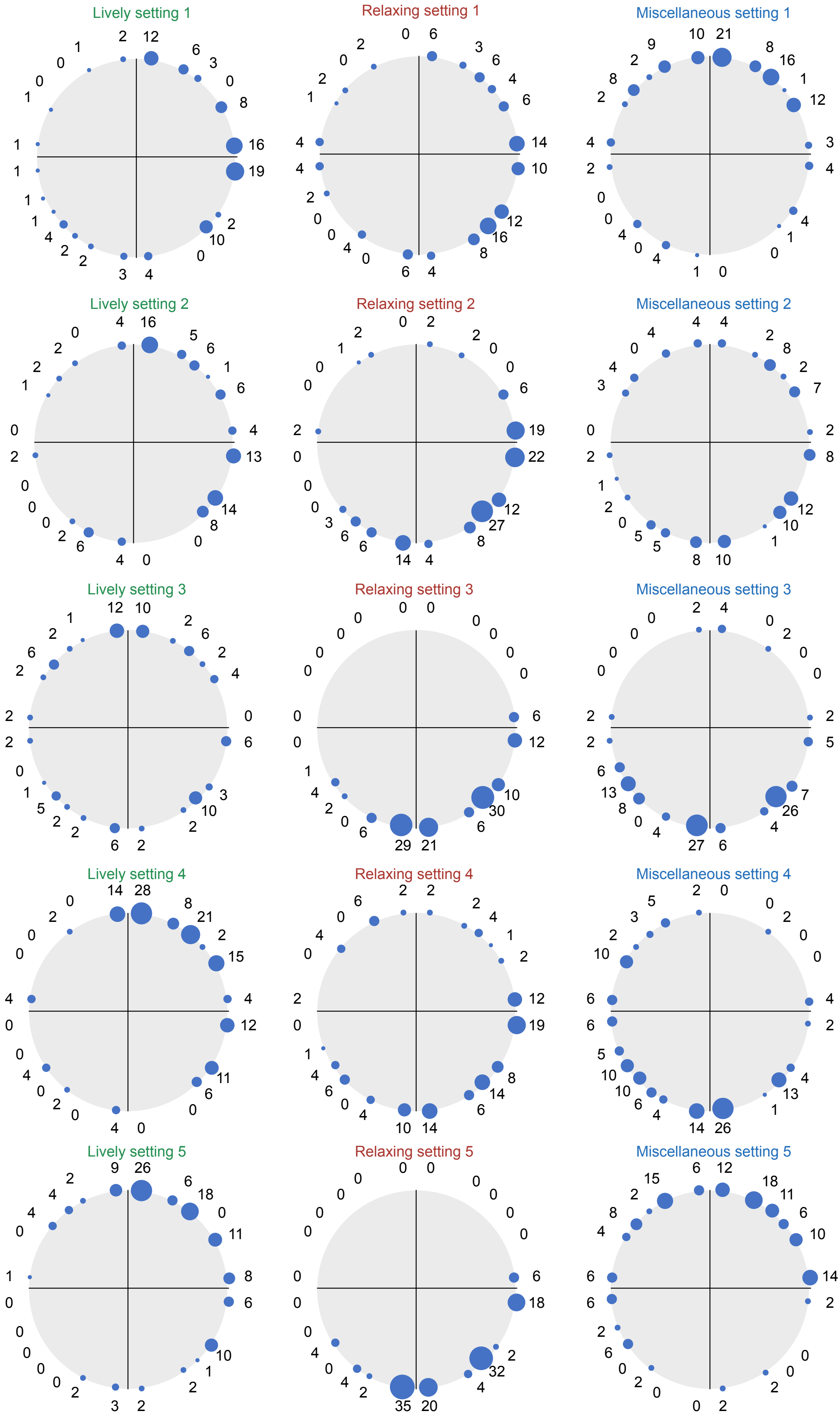


Figure 7.18. Perceived emotions under fifteen light settings on the circumplex model of affect.

7.2 Comparison between two emotion results

This section has discussed the results and findings of perceived emotions, which were assessed by two different methods. In this section, the results from two different methods are compared to further investigate human emotional responses of light and lighting.

7.2.1 Lively settings

Figure 7.19 illustrates two different sets of perceived emotions under five lively settings. The figures on the left-hand side show the results on Affect Grid and figures on the right-hand side show the results on the circumplex model of affect.

First, the results from perceived pleasantness and sleepiness (left-hand side figures) indicate large variability of responses under lively settings. For example, mean scores of perceived pleasantness and sleepiness under L1 setting suggest that participants felt almost neutral in pleasantness and sleepiness. However, the result from the circumplex model of affect shows that frequent reports of pleasantness along with less frequencies in activation, pleasant activation, and pleasant sleepiness. Considering that L1 was generally described as bright and visually interesting (see Figure 6.1), the result from the circumplex model of affect appears to be more logical. Under lively setting 2, again huge individual difference on perceived pleasantness was noticed on the affect grid. On the other hand, the result from the circumplex model of affect shows similar pattern to L1 but less frequency in ‘delightful’ and more frequency in ‘satisfying’. Considering that L2 was described as less visually interesting than L1 (see Figure 6.2), the circumplex model of affect seems again more appropriate for emotion measurement.

The results of perceived emotions under L3 suggest a similar finding. It is difficult to judge that either a pleasant emotion or an unpleasant emotion was particularly stimulated due to huge variation in perceived pleasantness. In fact, perceived appearance of L3 also shows non-normal distribution, too (see Figure 6.3). Perceived brightness, uniformity and visual interest were all largely varied under this setting. Under L4 and L5 setting, both results suggest that human emotion of pleasant activation was stimulated by luminous conditions. However, the results on the circumplex model of affect indicate more in-detail statement of stimulated human emotion. According to the circumplex model of affect, L4 resulted in more frequent emotions of activation, pleasant activation, and pleasant sleepiness compared to perceived emotion under L5.

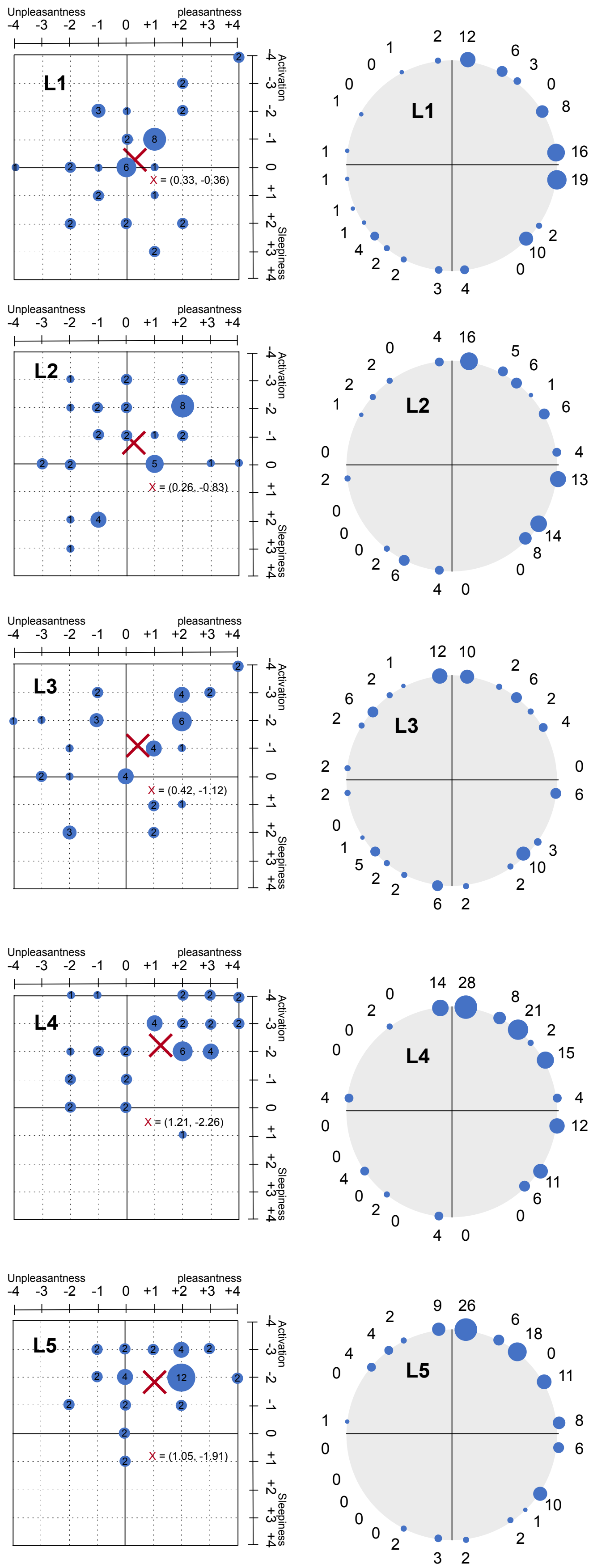


Figure 7.19. Perceived emotions under lively settings through two different methods (left-hand side figure: Affect Grid, right-hand side figure: the circumplex mode of affect). X denotes mean value on each scale.

What can be argued by comparison of the emotion results of lively settings are that mean scores of pleasantness and sleepiness did not provide an in-detail statement of perceived human emotion by lighting stimuli, particularly perceived pleasantness. Much of the literature has interpreted such results as due to a large individual difference in emotion, which may be the case. However, the results on the circumplex model of affect suggest that lighting (or luminous environment) could stimulate several zones of human emotion such as pleasant sleepiness, unpleasant sleepiness, and pleasant activation simultaneously. In these cases, perceived pleasantness and sleepiness tend to vary greatly. However, there were also some cases such L4 and L5 where participants' perceived pleasantness and sleepiness showed a clear grouping. In these case, it could be explained that the lighting stimulated clearly certain zone(s) of human emotion.

7.2.2 Relaxing settings

Perceived emotions (or affect) under five relaxing settings by two different methods are illustrated in Figure 7.20. Under relaxing settings, two emotion results, in general, provided much more similar findings than the results under lively settings. For example, perceived pleasantness and sleepiness under R3 and R5 clearly indicates that most participants felt pleasant sleepiness during the experience, which matches the results from the circumplex model of affect. According to the results on the circumplex model of affect, R5 stimulated more frequent responses of human emotion of pleasantness and sleepiness than R3 where participants more frequently reported their feelings of pleasant sleepiness. Under R2 and R4, both results also show similar finding. Under R2 setting, the circumplex model of affect shows that participants reported their emotion of sleepiness less frequently than R3 and R5, which was also found on the result from the affect grid. Under R4, a greater number of participants reported unpleasant sleepiness than R3 and R5, which is noticed in both results. Based on these results, the following arguments could be made for perceived emotions under relaxing settings. First, as spotted from lively settings, mean scores of pleasantness and sleepiness did not provide an in-detail statement of the impacts of lighting on human emotion or affect. Especially, when the mean value of perceived pleasantness was close to the neutral level with a large standard deviation, it would probably mean that lighting stimulated several emotion zones such as pleasant sleepiness, unpleasantness, and unpleasant sleepiness.

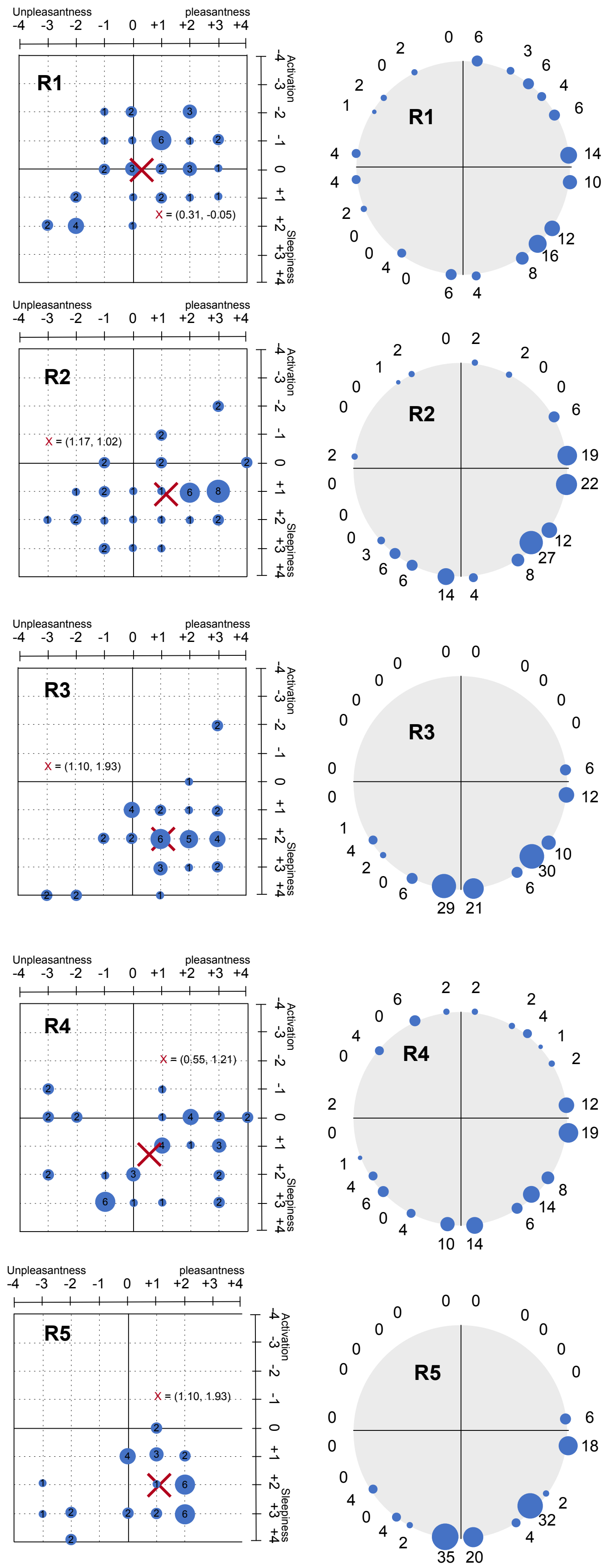


Figure 7.20. Perceived emotions under relaxing settings through two different methods (left-hand side figure: Affect Grid, right-hand side figure: the circumplex mode of affect). X denotes mean value on each scale.

However, in general, under relaxing setting, the results of perceived pleasantness and sleepiness match well with the results on the circumplex model of affect as can be seen from the cases of R2, R3, R4, and R5. The study argues that it is because the human emotion of pleasantness/sleepiness (regarded as pleasant sleepiness) is easily stimulated by most of lighting conditions. For example, as shown in Figure 7.20, one difference between R1 and the rest of relaxing settings was that under R1 setting there many participants who reported a degree of activation whereas under the rest of relaxing settings, only few or no participant(s) reported a degree of activation.

To summarise, perceived pleasantness and sleepiness values account for the impacts of lighting on human emotion when there is only a clear pattern in either activation or sleepiness. If the values show close to the neutral, the results would likely to be interpreted as a large variety of the responses in emotion. The emotion results of the circumplex model of affect could become a supplementary tool to understand the impacts of lighting on human emotion in that case.

7.2.3 Miscellaneous settings

Perceived emotions under miscellaneous settings by two different methods were also compared, which is shown in Figure 7.21. Under M1 setting, both results show that human emotion of activation was mainly stimulated under this setting. Interestingly, although the result on the circumplex model of affect did not seem to be particularly negative, perceived pleasantness values show a clear trend in unpleasant emotion. Similarly, under M5 setting, perceived pleasantness values indicate that majority of participants reported a degree of unpleasantness although the result on the circumplex model shows both positive and negative emotion.

Based on these two settings, an important finding on interpreting the results of the circumplex model could be argued. It seems that when there are significant frequencies of negative emotions (on the circumplex model of affect) under a luminous environment, an interpretation of such a result would need to put more weighting on negative emotions even if there are also significant numbers of positive feelings. In other words, it would be difficult to find a situation where lighting stimulates only negative (unpleasant) human emotion at least in a workspace environment.

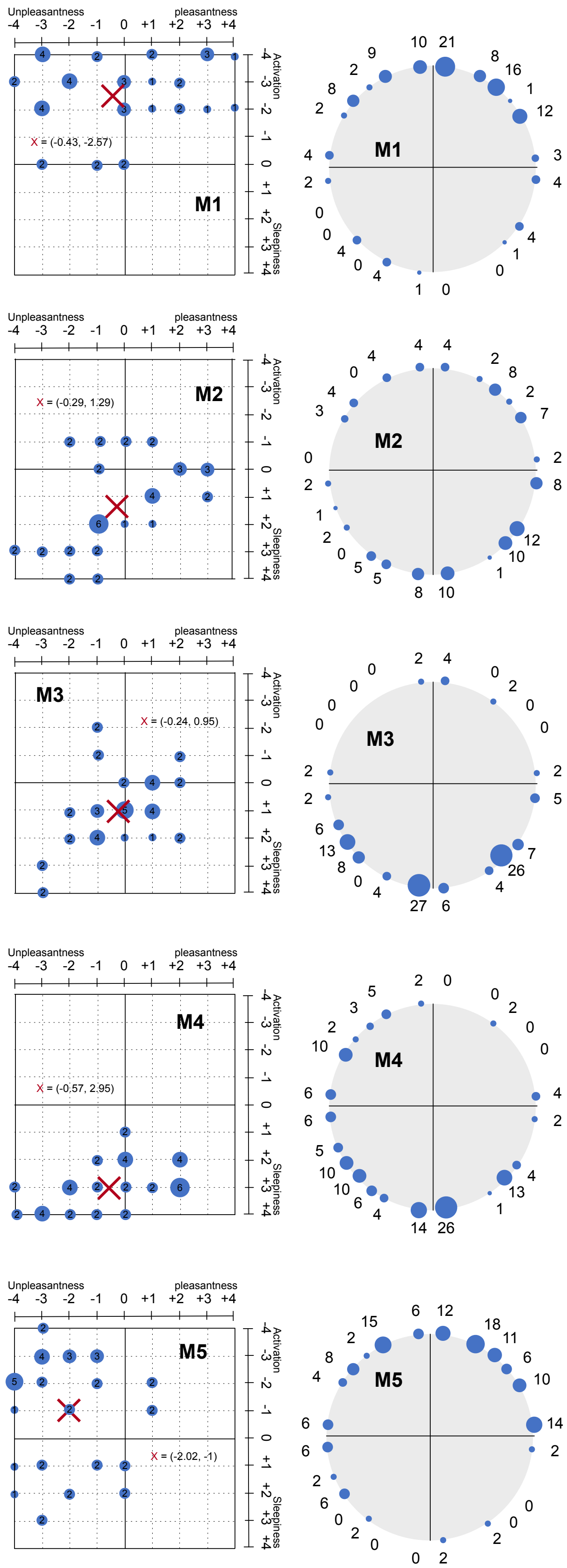


Figure 7.21. Perceived emotions under miscellaneous settings through two different methods (left-hand side figure: Affect Grid, right-hand side figure: the circumplex mode of affect). X denotes mean value on each scale.

It is again noticed that mean scores of pleasantness and sleepiness did not account for the impacts of lighting on human emotion under miscellaneous settings. Under M2 and M4 settings, for instance, mean values of participants' perceived pleasantness and sleepiness suggest that the respondents reported similar feelings. However, the results on the circumplex model of affect show that the impacts of two light settings on human emotion were very different.

7.2.4 A classification of emotion quality

This sub-chapter has so far compared the two emotion results under fifteen light settings. Based on the findings, a classification of perceived emotion quality could be made. Figure 7.22 illustrates fifteen perceived emotions (on the circumplex model of affect) in four different groups, 'good', 'indifferent to good', 'indifferent to bad', and 'bad'. As shown in Figure 7.60(a), L4, L5, R2, R3, and R5 were classified as good quality of perceived emotions among the fifteen emotions. The characteristics of this group is that firstly lighting strongly stimulated human emotion of either activation (L4, L5) or sleepiness (R2, R3, R5). Second, perceived emotions under these settings mostly consisted of positive (pleasant) feelings. For example, L4, and L5 stimulated activation, pleasant activation, pleasantness, and pleasant sleepiness of human emotion. R2, R3, and R5 stimulated pleasantness, pleasant sleepiness and sleepiness. The light settings that belong to the second group, which is classified as 'indifferent to good quality' have the common characteristic that although pleasant feelings were stimulated by lighting, reported numbers of such feelings were less than the settings from the first group. Also, more numbers of unpleasant feelings or affects were reported than the settings in the first group.

Thirdly, M1, M2 and M3 settings were grouped as 'indifferent to bad' quality of perceived emotion. There are several features of perceived emotions that are found under these settings. First, these light settings stimulated almost no human emotion of pleasantness and unpleasantness. For example, respondents' feelings under M1 were consisted of unpleasant activation, activation and pleasant activation. In opposition to this, under M3 light setting, participants felt unpleasant sleepiness, sleepiness and pleasant sleepiness. Lastly, M4 and M5 were classified as bad quality of emotions. Perceived emotions under M4 could easily be judged as 'bad' quality since reported feelings were mostly related to unpleasantness, unpleasant sleepiness and unpleasant activation. Quality of perceived feelings under M5 is difficult to be judged by only looking at the results on the circumplex model of affect. This study suspects that this is perhaps because M5 stimulated a perceived feeling of 'exciting' inappropriately high for a workspace environment, which consequently resulted in high numbers of reported feelings of unpleasant activation and unpleasantness. The results and findings of perceived emotions under fifteen light setting were now all discussed in this chapter. Although the main focus of second phase of the field study was to investigate the impacts of lively, relaxing and miscellaneous settings on perceived appearance and emotion, the study has also included environmental satisfaction and eyestrain as dependent variables, and the results of these are discussed in following section of this chapter.

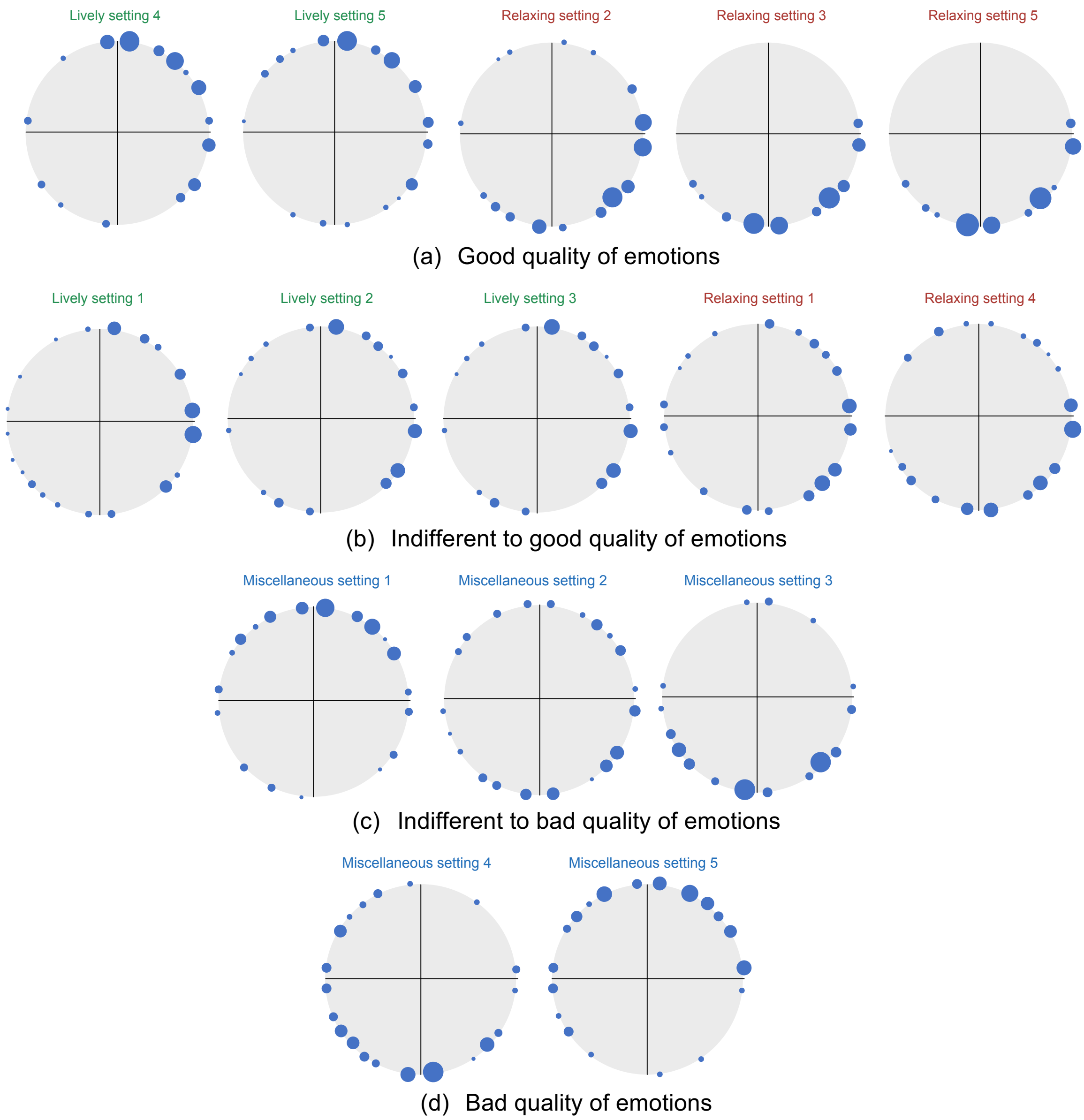


Figure 7.22. A classification of emotion qualities under fifteen light settings into four groups.

Chapter 8

Result and findings from the experiment: Part III

This chapter reports the results and the findings of perceived environmental satisfaction and eyestrain under fifteen light settings obtained from the controlled study. Since most of aims and objectives of the study are to investigate an impact of lighting on human emotion, this chapter relatively briefly describes the results compared to the earlier two chapters.

8.1 Environmental satisfaction

Environmental satisfaction levels under each light setting were self-assessed by five items with a 5-point Likert rating, as previously introduced in Chapter 3 (Figure 3.12). This section explains the results and findings of lively, relaxing and miscellaneous settings in their respective order.

8.1.1 Lively settings

Figure 8.1 shows perceived environmental satisfaction levels under five lively settings with calculated mean values and standard deviation (SD) values. Unlike perceived appearance of the space or reported emotions during the experiment, only small variations in perceived environmental satisfaction levels among lively settings were found.

More specifically, in relation with perceived attractiveness from the presence of lighting, L4 setting was most frequently rated as more attractive (based on mean values) than the other four lively settings which were all perceived at a similar quality of attractiveness. When it comes to colour appearances of the space and perceived levels of attractiveness, the results indicate that L1 and L4 were most frequently rated as more attractive than the other three settings. In terms of perceived comfort levels, participants, on average, agreed that they would consider the spaces as comfortably lit workspaces under all lively settings. The similar results were found for perceived overall satisfaction of the space. The results also show that all lively settings would be suitable for a use of a meeting or a conference as most of, many of participants reported a good rendering quality of persons sitting next to them.

Overall, it could be said that all the lively settings provided visually comfortable and satisfying workspace environments and especially L4 setting was more frequently perceived as an attractive space than other lively luminous environments. Since lively settings were all designed by professional lighting designers, such results were well-expected. In the next section, perceived environmental satisfaction levels under relaxing settings are explained. One possible limitation with the results in Figure 8.1 is the effect of a middle response category. Such a trend seems to be noticed, particularly on the items of ‘satisfaction’ and ‘visual comfort’. If the study provided the participants with an even number of Likert scaling, such a pattern might have been avoided.

		1 Not at all	2 A little	3 Moderately	4 Very much	5 Completely	Mean (SD)
Does the presence of the lighting make the space more attractive?	L1	8	12	20	2	0	2.38 (0.86)
	L2	9	13	12	8	0	2.45 (1.03)
	L3	6	17	9	6	0	2.39 (0.96)
	L4	4	14	10	12	2	2.86 (1.12)
	L5	12	14	10	6	0	2.24 (1.04)
Does the colour appearance of the lightings make the room more attractive?	L1	6	6	18	9	3	2.93 (1.09)
	L2	12	15	9	6	0	2.21 (1.03)
	L3	11	13	4	10	0	2.34 (1.20)
	L4	6	13	5	8	10	3.07 (1.47)
	L5	16	10	8	7	1	2.21 (1.26)
Overall, would you consider this workspace comfortably lit if you were staying for a few hours?	L1	4	14	6	12	6	3.05 (1.28)
	L2	4	8	12	12	6	3.19 (1.21)
	L3	5	7	14	6	6	3.03 (1.29)
	L4	4	6	16	9	7	3.21 (1.17)
	L5	4	6	10	15	7	3.35 (1.20)
Overall, how satisfied are you with lighting in the space?	L1	2	8	22	8	2	3.00 (0.89)
	L2	4	12	14	8	4	2.90 (1.14)
	L3	4	8	16	10	0	2.84 (0.96)
	L4	4	6	11	14	7	3.33 (1.19)
	L5	0	6	18	18	0	3.29 (0.72)
How does the lighting render the person sitting next you (for conference use)?	L1	0	0	14	24	4	3.76 (0.62)
	L2	0	2	8	18	14	4.05 (0.86)
	L3	0	2	16	16	4	3.58 (0.89)
	L4	0	0	6	14	22	4.38 (0.74)
	L5	0	0	8	15	19	4.26 (0.77)

Figure 8.1. Perceived environmental satisfaction levels with mean and standard deviation (SD) values under lively settings

8.1.2 Relaxing settings

Perceived environmental satisfaction levels under five relaxing settings are shown in Figure 8.2 with calculated mean and standard deviation values. In terms of perceived attractiveness from the presence of lighting and colour appearance, the results in the below figure indicate that all relaxing settings were perceived as more attractive than the default setting, which was turned on before the experiment. Like the results under lively settings, relaxing settings were also perceived as generally satisfying and visually comfortable to be used as a workspace environment except for R4 setting, where participants reported a lesser number of visual comfort than other relaxing settings.

Lastly, it was also found that participants generally reported a lower quality of facial rendering under relaxing settings than lively settings. Based on that it could be said that lively settings would be more suitable for a space where visual communication is an important part of daily tasks. Instead, relaxing settings would be more suitable for the use of individual work or study area where feelings of ‘calm’ and ‘quiet’ would be required.

8.1.3 Miscellaneous settings

Participants’ perceived levels of environmental satisfaction under five miscellaneous settings are also analysed and the result is shown in Figure 8.3. M1 setting was described as attractive least frequently among the five miscellaneous settings. The results of M5 on the first two questions show that either participants felt significant attractiveness from the lighting and its colour appearance or felt no attractiveness at all. As explained earlier, it was found that although M5 was perceived as highly visually interesting, the type of visual interest was clearly not suitable for a context of workspace environment. The study suspects this is the reason why participants had such a split perception on attractiveness under M5. As expected, overall lower perceptions of visual comfort were found under all the miscellaneous settings compared to lively and relaxing settings. Such a result is well matched by earlier results and findings on bad qualities of perceived emotions under these settings. The fact that miscellaneous settings were neither created by the designers nor intended to be a workspace environment generated generally low levels of environmental satisfaction.

Does the presence of the lighting make the space more attractive?

	1 Not at all	2 A little	3 Moderately	4 Very much	5 Completely	Mean (SD)
R1	4	16	12	10	0	2.67 (0.97)
R2	2	12	10	16	2	3.10 (1.04)
R3	0	16	18	8	0	2.81 (0.75)
R4	6	6	11	19	0	3.02 (1.12)
R5	4	13	15	8	2	2.79 (1.04)

Does the colour appearance of the lightings make the room more attractive?

	Not at all	A little	Moderately	Very much	Completely	Mean (SD)
R1	6	8	13	11	4	2.97 (1.20)
R2	4	10	10	14	4	3.10 (1.18)
R3	4	18	12	6	2	2.62 (1.02)
R4	10	4	10	16	2	2.90 (1.30)
R5	6	12	15	7	2	2.69 (1.06)

Overall, would you consider this workspace comfortably lit if you were staying for a few hours?

	Not at all	A little	Moderately	Very much	Completely	Mean (SD)
R1	4	14	16	4	4	2.76 (1.09)
R2	6	12	12	8	4	2.81 (1.21)
R3	5	9	12	12	4	3.02 (1.22)
R4	10	14	12	6	0	2.33 (1.02)
R5	4	12	14	10	2	2.86 (1.06)

Overall, how satisfied are you with lighting in the space?

	Not at all	A little	Moderately	Very much	Completely	Mean (SD)
R1	2	14	16	8	2	2.86 (0.96)
R2	2	10	12	18	0	3.10 (0.94)
R3	2	11	13	14	2	3.07 (1.02)
R4	4	14	10	14	0	2.81 (1.03)
R5	0	14	14	12	2	3.05 (0.92)

How does the lighting render the person sitting next you (for conference use)?

	Not at all	A little	Moderately	Very much	Completely	Mean (SD)
R1	0	5	15	16	4	3.48 (0.89)
R2	0	4	18	14	6	3.52 (0.87)
R3	0	10	22	10	0	3.00 (0.71)
R4	2	6	20	14	0	3.10 (0.83)
R5	0	24	16	2	0	2.48 (0.60)

Figure 8.2. Perceived environmental satisfaction levels with mean and standard deviation (SD) values under relaxing settings

Question		1 Not at all	2 A little	3 Moderately	4 Very much	5 Completely	Mean (SD)
Does the presence of the lighting make the space more attractive?	M1	9	19	6	2	4	2.32 (1.18)
	M2	11	13	13	5	0	2.29 (1.06)
	M3	4	14	20	4	0	2.57 (0.81)
	M4	12	10	10	8	2	2.48 (1.25)
	M5	14	8	4	10	6	2.67 (1.53)
Does the colour appearance of the lightings make the room more attractive?	M1	14	16	6	2	2	2.05 (1.10)
	M2	12	14	8	8	0	2.29 (1.10)
	M3	6	22	8	6	0	2.33 (0.91)
	M4	8	20	8	4	2	2.33 (1.06)
	M5	14	4	6	8	10	2.90 (1.64)
Overall, would you consider this workspace comfortably lit if you were staying for a few hours?	M1	9	13	8	10	0	2.48 (1.10)
	M2	12	16	6	6	2	2.29 (1.19)
	M3	8	14	12	8	0	2.48 (1.03)
	M4	20	9	11	2	0	1.88 (1.00)
	M5	32	8	2	0	0	1.29 (0.53)
Overall, how satisfied are you with lighting in the space?	M1	10	10	12	6	2	2.50 (1.19)
	M2	5	21	8	8	0	2.45 (0.98)
	M3	2	16	14	10	0	2.76 (0.89)
	M4	8	22	4	8	0	2.29 (1.01)
	M5	24	16	1	1	0	1.50 (0.61)
How does the lighting render the person sitting next you (for conference use)?	M1	0	0	3	11	26	4.58 (0.69)
	M2	0	5	19	16	2	3.36 (0.80)
	M3	0	16	22	2	0	2.65 (0.59)
	M4	12	18	12	0	0	2.00 (0.87)
	M5	6	15	17	4	0	2.45 (0.87)

Figure 8.3. Perceived environmental satisfaction levels with mean and standard deviation (SD) values under miscellaneous settings

8.2 Eyestrain

Lastly, as explained in Chapter 3, participants self-reported their perceived eyestrain by four-item questions with 5-point Likert scale after each light setting. This section explains the results and findings from the results in an order of lively, relaxing, and miscellaneous settings.

8.2.1 Lively settings

Figure 8.4 illustrates the results of perceived eyestrain under lively settings. First, as can easily be noticed from the result, there was no significantly reported eyestrain under any of lively settings. Although no lively settings evoked significant symptoms of eyestrain, this study has noticed two features from the result. First, participants reported the symptom of tired eyes more frequently than other items in the questionnaire, especially, the symptom of redness (or soreness) and dryness of in the eyes. Second, under L3 setting, participants reported more frequently of their perceived eyestrain than other settings. The study then looked at the result of perceived eyestrain under relaxing settings.

8.2.2 Relaxing settings

The results of perceived eyestrain under relaxing settings are shown in Figure 8.5. Again it is noticed that almost no perceived eyestrain was found under all relaxing settings. Compared to lively settings, no particular increase or decrease in perception of eyestrain was noticed. Although mean values of perceived eyestrain suggest that the respondents' perceived eyestrain was least frequently occurring under R2 setting, the difference between the other settings was only marginal. Interestingly, like the results under lively settings, there seemed to be more frequent reports of tired eyes than the other three symptoms. Overall, it could be argued that both lively and relaxing settings did not evoke particular eyestrain during the experiment.

8.2.3 Miscellaneous settings

Lastly, perceived eyestrain under five miscellaneous settings is also analysed and the result is shown in Figure 8.6. The result shows that under M1 and M5 settings, participants felt more negativity to light from eye discomfort as well as experiencing tired eyes. Several findings could be drawn from this result. First, combining high light level with over 6,000K of CCT lamps could lead to an increase of subjective feelings of negative sensitivity from eye discomfort and symptom of tired eyes. Second, even a luminous environment like M1 and M5 did not result in any significant increase in dryness, redness or soreness in the eyes. Therefore, when a lighting study considers the impacts of lighting on subjective feelings of perceived eyestrain, more attention should be paid to assess negative sensitivity from eye discomfort and tired eyes. Moreover, the result under M2 setting suggests that with a use of low CCT lamps (2,000K), level of light did not seem to be related with perceived feelings of eyestrain.

In summary, this chapter has explained the results of perceived environmental satisfaction and perceived eyestrain under fifteen light settings. In the next chapter, the overall summary of the study as well as its strength and weakness are finally discussed.

I am experiencing negative sensitivity to light from eye discomfort.	1 Not at all	2 A little	3 Moderately	4 Very much	5 Completely	Mean (SD)
L1	26	10	2	4	0	1.62 (1.06)
L2	22	15	5	0	0	1.60 (0.74)
L3	16	14	4	4	0	1.89 (0.99)
L4	26	11	3	2	0	1.55 (0.87)
L5	22	15	3	2	0	1.64 (0.86)

I am experiencing either of redness or soreness in the eyes.	Not at all	A little	Moderately	Very much	Completely	Mean (SD)
L1	32	8	0	1	1	1.36 (0.65)
L2	26	12	4	0	0	1.48 (0.68)
L3	23	11	2	2	0	1.55 (0.84)
L4	26	12	4	0	0	1.48 (0.68)
L5	24	11	7	0	0	1.60 (0.80)

I am experiencing tired eyes.	Not at all	A little	Moderately	Very much	Completely	Mean (SD)
L1	16	22	1	3	0	1.79 (0.87)
L2	12	26	4	0	0	1.81 (0.60)
L3	14	14	3	3	4	2.18 (1.30)
L4	19	17	6	0	0	1.69 (0.72)
L5	18	14	6	4	0	1.90 (1.00)

I am experiencing dryness in the eyes.	Not at all	A little	Moderately	Very much	Completely	Mean (SD)
L1	30	10	1	1	0	1.36 (0.74)
L2	25	15	2	0	0	1.45 (0.60)
L3	20	11	3	4	0	1.76 (1.03)
L4	30	6	4	2	0	1.48 (0.87)
L5	25	15	3	0	0	1.50 (0.68)

Figure 8.4. Perceived eyestrain with mean and standard deviation (SD) values under lively settings

I am experiencing negative sensitivity to light from eye discomfort.

	1 Not at all	2 A little	3 Moderately	4 Very much	5 Completely	Mean (SD)
R1	28	11	3	0	0	1.40 (0.68)
R2	33	7	2	0	0	1.26 (0.56)
R3	28	12	0	1	1	1.45 (0.93)
R4	28	10	3	1	0	1.45 (0.81)
R5	28	7	4	3	0	1.57 (1.15)

I am experiencing either of redness or soreness in the eyes.

	Not at all	A little	Moderately	Very much	Completely	
R1	26	10	6	0	0	1.52 (0.75)
R2	34	8	0	0	0	1.19 (0.40)
R3	30	10	2	0	0	1.33 (0.58)
R4	29	9	2	2	0	1.45 (0.81)
R5	32	8	1	1	0	1.31 (0.73)

I am experiencing tired eyes.

	Not at all	A little	Moderately	Very much	Completely	
R1	20	14	7	1	0	1.74 (0.89)
R2	30	8	3	1	0	1.41 (0.81)
R3	21	13	6	1	1	1.76 (1.04)
R4	18	16	4	4	0	1.86 (0.96)
R5	23	13	2	2	2	1.74 (1.19)

I am experiencing dryness in the eyes.

	Not at all	A little	Moderately	Very much	Completely	
R1	30	8	3	1	0	1.40 (0.81)
R2	31	7	2	2	0	1.41 (0.81)
R3	24	14	2	0	2	1.62 (0.97)
R4	30	7	5	0	0	1.40 (0.75)
R5	30	8	2	2	0	1.43 (0.81)

Figure 8.5. Perceived eyestrain with mean and standard deviation (SD) values under relaxing settings

I am experiencing negative sensitivity to light from eye discomfort.

	1 Not at all	2 A little	3 Moderately	4 Very much	5 Completely	Mean (SD)
M1	16	10	10	2	2	2.10 (1.17)
M2	24	12	6	0	0	1.57 (0.75)
M3	26	14	2	0	0	1.43 (0.60)
M4	22	15	3	2	0	1.64 (0.86)
M5	13	15	7	7	0	2.19 (1.12)

I am experiencing either of redness or soreness in the eyes.

	Not at all	A little	Moderately	Very much	Completely	
M1	22	13	3	2	0	1.62 (0.93)
M2	24	14	2	2	0	1.57 (0.81)
M3	28	9	5	0	0	1.45 (0.75)
M4	24	18	0	0	0	1.43 (0.51)
M5	14	22	4	2	0	1.86 (0.89)

I am experiencing tired eyes.

	Not at all	A little	Moderately	Very much	Completely	
M1	9	15	10	4	2	2.38 (1.14)
M2	16	16	6	3	1	1.98 (1.10)
M3	19	19	4	0	0	1.64 (0.66)
M4	16	22	2	2	0	1.76 (0.77)
M5	12	16	6	6	2	2.29 (1.19)

I am experiencing dryness in the eyes.

	Not at all	A little	Moderately	Very much	Completely	
M1	24	12	2	0	0	1.42 (0.61)
M2	30	5	5	2	0	1.50 (0.93)
M3	28	10	4	0	0	1.43 (0.68)
M4	29	11	1	1	0	1.38 (0.74)
M5	22	12	8	0	0	1.67 (0.80)

Figure 8.6. Perceived eyestrain with mean and standard deviation (SD) values under miscellaneous settings

Chapter 9

Conclusion and discussion

Finally, this chapter discusses conclusions and discussions obtained from the findings of the field study. This chapter first explains how this study addressed the research questions, which were set in the Introduction. Then, a self-reflection of the strengths and limitations of the study is explained and potential implications of the findings to industry are briefly discussed.

9.1 Responses to research questions

This study proposed four different research questions, which were as follows:

(1) *Could a set of lighting arrangements in the workspace cue various positive human emotion?*
(2) *Could smart lighting technology be embedded in the lighting design process to further explore such an opportunity?*
(3) *Could the study identify the elements of lighting design or luminous conditions which are associated with various human emotions?*
(4) *Do the current assessment tools used in lighting studies effectively explain the human psychological responses to dynamic light settings?*

First, has this study found whether human positive emotions can be stimulated by a set of lighting arrangements in the workspace? The answer is yes. As explained and discussed in Chapter 6 and Chapter 7, the human emotion of ‘pleasantness-unpleasantness’ and ‘activation-sleepiness’ was extensively explored under fifteen lighting settings, which consisted of five ‘lively’, five ‘relaxing’, and five additional ‘miscellaneous’ settings. Five out of the fifteen settings, consisting of two lively settings and three relaxing settings, were found to be particularly associated with the desired pattern (or trend) of human emotion defined by this study.

Second, has the study found whether smart lighting technology can have the potential to further explore such emotion-based lighting design? The answer is yes, but depends on the context. Many attempts by the lighting designers to accommodate smart lighting technology within their design concepts to create a dynamic lighting effect were noticed. However, not all of their efforts ended up with an improvement in participants' emotional experiences. The results suggest that dynamic light settings have the potential to effectively achieve the human emotion of 'lively' (defined as 'both pleasing and activating') if properly applied, whereas the human emotion of 'relaxing' (defined as 'both pleasing and sleepy') seems to be associated with a non-dynamic luminous environment with generally warm appearance of the space. The study also found that if such technology is carelessly applied in the workspace lighting design, it could lead to a high level of unpleasantness felt by the occupants.

Third, has the field study identified any elements of the lighting design or luminous condition that are associated with human emotion? Again, the answer is yes but only up to a certain extent. Out of the fifteen light settings, only two lighting arrangements created a clear trend in the perceived emotions to be considered 'lively'. These two settings had a common design characteristic that was rather particular in their luminous environments. Both settings included the use of a colour loop that changed its colour properties from saturated blue to cyan to create a directional pattern on the wall surface. Based on this finding, it could be described that such lighting pattern caused by the coloured lights is associated with the human emotion of 'both pleasing and activating'. However, such emotional impacts caused by lighting design elements were not effectively explained by any of recorded photometric and colorimetric variables. The human emotion of 'activation-sleepiness' was also strongly explored and influenced by lighting elements. Unlike the findings of 'lively' and 'relaxing', stimulating the human emotion of activation did not seem to require particular design elements. Perceived activation level varied effectively when lighting condition was from a CCT value of 2000K to a CCT of 6500K.

Fourth, has the study found that the current assessment tools used in lighting studies effectively explain the human psychological responses to dynamic light settings? The answer is not quite. Although the human emotion of pleasantness/unpleasantness and activation/sleepiness was largely explored by fifteen light settings, the current measure of human emotion with scores of key dimensions shows also some limitation in providing an in-detail statement of the impacts of lighting on human emotion. For example, two completely different luminous environments, one with a high light level with very warm CCT lamps and the other with a low light level with very cool CCT lamps, resulted in a very similar level of pleasantness and sleepiness although their perceived appearances were found to be markedly different. In this matter, the emotion descriptors, derived from the circumplex model of affect, showed a more in-detail statement of the impacts of lighting on human emotion by showing the shape of stimulated zones of human emotion.

The study also looked at perceived levels of environmental satisfaction and subjective feelings of eyestrain under fifteen light settings. The results showed that participants generally described the feeling of comfortably lit and satisfied with the surrounding environment under all of the designers' inspired settings whereas the five miscellaneous settings showed slightly worse perceptions in this matter.

Overall, the study successfully explored the possibilities of an emotion-based lighting design approach and explained their impacts by a controlled experiment. The results suggest that human emotion of 'lively' and 'relaxing' can be stimulated by a set of lighting arrangements. A self-reflection section follows which discusses the strength and limitations of the work.

9.2 Self-reflection: strengths and limitations

One encouraging feature from this study is that (1) some of the findings from the literature have been verified and (2) the results of this study provide a further explanation of the existing findings. More specifically, five miscellaneous settings were created with an intention to verify the findings from the literature. An exposure of bright light is often argued to increase both physiological and psychological activation level (Küller and Wetterberg, 1993; Smolders and de Kort, 2013) even during office hours (Smolders et al., 2012). Further, similar impacts on human activation level are also found under an exposure to blue-enriched lights (Viola et al., 2008). As shown in Figure 8.1, which is a reproduction of Figure 7.37, the result under miscellaneous setting 1 shows similar findings to the studies mentioned above. Majority of participants reported a very high degree of activation under a high light level and high CCT lamps. Conversely, the majority of respondents reported a high degree of sleepiness under a low light level and low CCT lamps.

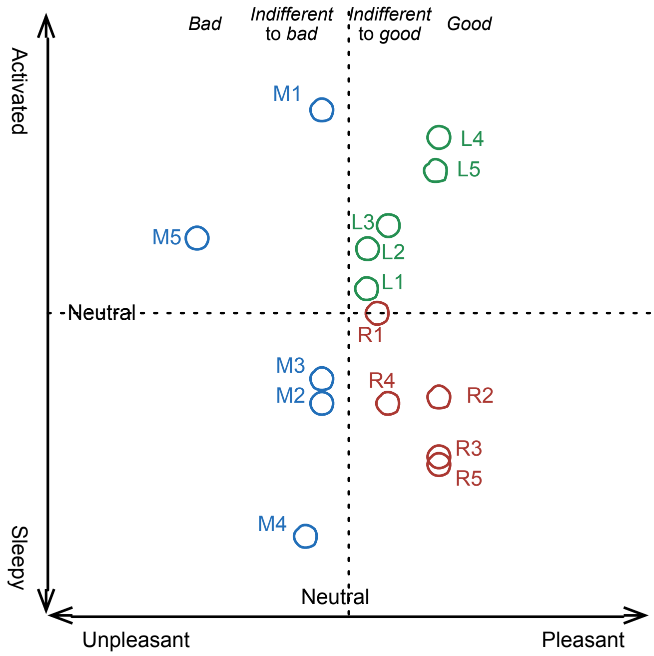


Figure 9.1. Classification of lighting quality and its relationship with perceived emotions under fifteen light settings on the circumplex model of affect

It is also clearly found that modifying CCT (M1M2, M3/M4) or illuminance (M1/M3, M2/M4) did not have an impact on perceived pleasantness or unpleasantness. Only the subjective level of activation/sleepiness was influenced by such changes in luminous environments. Even a change of both illuminance and CCT together (M1/M4) did not show a significant impact on perceived pleasantness. This result explains why much of the literature using the PANAS model has shown inconsistent results.

According to Barrett and Russell (1999), Positive Affect (PA) is a combination of pleasantness and high activation and Negative Affect (NA) is a combination of unpleasantness and high activation. Therefore, if there is no change in the perceived pleasantness/unpleasantness level, measuring the impacts of lighting on human emotion through a PANAS scale could lead to a misinterpretation of such results.

Lastly, this study has related the results of perceived emotion back to Boyce (2003)'s formulation of 'good', 'indifferent' and 'bad' quality of lighting. As shown in Figure 8.1, the concept of lighting quality applies well to the circumplex model of affect. If a lighting installation resulted in its occupants feeling neutral to slightly pleasant, it could be classified as 'indifferent-to-good' quality. If a clear emotion pattern of 'lively' or 'relaxing' is reported, then the quality of a lighting installation could be judged as 'good'. As the study argued earlier in this thesis, promoting positive human emotion by lighting is shown to bridge the gap between 'indifferent' and 'good' quality lighting.

However, there are also some limitations in this study. Since this study claims to be the first to explore an emotion-based lighting design using the concept of the circumplex model of affect, several further studies in this matter are required to enhance the findings of this study. Further, the designers' ideas of lively and relaxing workspace concepts could not be generalised. Again, many further studies that involve lighting designers' exploring their concepts of emotion-based designs, preferably with smart lighting technology, are required to gather more ideas on human emotion by lighting from designers' perspective of view.

9.3 Potential implications

Before finishing the thesis, the author would like to discuss its implications to both the lighting design industry and lighting research.

It has been shown that all the participating designers know how to create a workspace lit environment that provides both visually comfortable and a good feelings of satisfaction to its occupants even without following any of the recommendations or standards. Therefore, designing a lit environment with a focus on occupants' emotional needs could not lead to any potential loss in terms of quality of lighting. It was found that a colour of saturated blue and cyan was associated with a feeling of 'lively', especially when they were smartly controlled. Therefore, designers could consider using such coloured effects as accent lighting when designing a workspace lit environment that promotes a pleasantly activating atmosphere. However, an excessive use of colored lights with smart control technology could easily lead to a high degree of visual interest but would result in very unpleasant feelings to its occupants as in the case of miscellaneous setting 5. If a designer wishes to create a workspace that provides a high degree of relaxation to its occupants, the results suggest that it would be worth considering using a CCT of 2,700K to 3,000K lamps as well as using a lampshade to provide a slightly diffused appearance. Perhaps, the use of smart lighting technology would not be so necessary in this matter although exploration of such an option would also be worthwhile.

It seems that the current widely used photometric and colorimetric characteristics of lit environments do not describe our feelings and some of the appearances of the space, especially when smart lighting control provides several coloured lights simultaneously. Therefore, further studies to broaden our knowledge of describing the dynamic luminous environment should be followed as it is likely that developments in lighting control technology will rapidly increase.

Lynes (1996; 2013) argued that lighting is not an art, not a science but rather a language. In this sense, we are now being given an opportunity to invent a new ‘language of light’, a non-verbal communication of not only expressing our preferred appearance but also expressing our preferred emotions. For a long period, our vocabulary extensively focused on describing the appearance of the space, which is without doubt, one of the most crucial part of the language. Hopefully, this study would lead an ignition of interest in the development of our vocabulary of human emotion in lighting.

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Appendices

Appendix 1

Participant information sheet

The Bartlett School of Environment, Energy and Resources
Institute for Environmental Design and Engineering
14 Upper Woburn Place, London, WC1H 0NN

LIGHT, EMOTION AND INTERACTION:
EXPLORING HUMAN AFFECT IN LIGHTING

PARTICIPANT INFORMATION SHEET

(1) What is this study about?

You are invited to take part in a research study about exploring the impact of the digital revolution in lighting technology on users various experiences. This study first aim to investigate the impacts of the recent development in lighting technology on office lit environment and then analyse the impacts on users experiences. Therefore the study could build a theoretical and practical guideline on an intelligent lighting system that interacts with users experiences in order to enhance users' well-being.

You have been invited to participate, either because you are an expert in this field or have shown interest in this study. This statement specifies the details of research, and will therefore help you decide if you want to take part in the experiment. Please read this sheet carefully and do not hesitate asking any further questions.

Participation in this research study is voluntary.

By giving consent to take part in this study, you are acknowledging that you:
- ✓ Understand what you have read.
- ✓ Agree to take part in the research study as outlined below.
- ✓ Agree to the use of your personal information as described.

You will be given a copy of this Participant Information Statement for keeping.

(2) Who runs the study?

The study is carried out by:
- Dong Hyun Kim, PhD candidate, IEDE, UCL.

Dong Hyun Kim is conducting this study for the degree of PhD at University College London. He and this study are under the supervision of Dr. Kevin Mansfield, and Peter Raynham, at the Bartlett School of Environment, Energy and Resources.

Participation Information Sheet Page 1 Version: 1.0 Date: 22-05-15

(3) What does this study involve?

- ✓ The field study is sub-divided into two phases; Phase I targets lighting designers and Phase II targets general users.
- ✓ In Phase I, lighting designers will first be asked to explore the experimental space and lighting fittings for approximately an hour with the guidance of the researcher and then be asked to create their own lighting design proposals of 'Relaxing' and 'Lively' lit environment later.
- ✓ In Phase II, various users (preferably non-lighting designers) will be asked to participate in a field experiment, which entails computer screen-based visual tasks, and questionnaires that would approximately take two and half hours in total.

(4) How long will the study take?

The Phase I expects to take approximately two weeks for the lighting designers to come up with their proposals then the Phase II (the field experiment) expects to take approximately five weeks (three hours per day and three to four times per week). The location of the experimental space is the Jevons room, which is on the first floor of the Central House in London. The address of the premise is 14 Upper Woburn Place, London, WC1X 0NN in the UK.

(5) Is it possible to withdraw from the study once I have started?

Participation in this study is completely voluntary. Your decision to participate will not affect your current or future relationship with the researcher or anyone at University College London.

You are free to withdraw from the experiment if you decided to take part in the study and then changed your mind later.

You are also not obliged to answer any of the questions should you feel uncomfortable during the field study.

(6) Is there any risk or cost involved in the study?

Aside from your sparing time, the researcher does not expect that there will be any risk or cost involved in the study.

(7) Is there any benefit for participants?
The expected benefit of the field study is first to conceptualize and develop a future intelligent lighting system that could enhance the users' overall experiences and well-being.

Apart from the academic achievement, each participant will be paid at the rate of £8/hour upon the end of experiment.

(8) What will happen to information collected during the study?

- ✓ Information about participants will be recorded, collected and used in the study. They include the transcripts and/or recording of the test result.
- ✓ Your data will only be used for analysis, which will be part of future publication including PhD thesis, journal article and conference presentation. However, your individual identity will not be revealed in any of the publications.
- ✓ Your personal information will be kept strictly confidential, and only be shared with research team members.
- ✓ All data will be stored in the researcher's own laptop. Only the researcher will have access to your data.

By providing consent, you agree to the aforesaid points. Your personal information and all data collected will only be used for the purposes outlined in this Participant Consent Statement.

(9) What if I would like further information about the study?

Dong Hyun Kim will be available to discuss further with you and answer any question you may have with regard to the field study. Please feel free to reach Dong Hyun Kim at: dong.kim@ucl.ac.uk or +44 7837 980233.

(10) Will I be told about the results of the study?

You have the right to receive information about the findings of the study. You can also notify the researcher in advance that you hope to receive information about the study once it is complete.

If you have read the statement and agree to give consent, please type your name below in lieu of signature:

……………………………….	……………………………….	…………………………….
Signed by Participant	Signed by Principal researcher	Date

Appendix 2

Gift agreement document

LONDON'S GLOBAL UNIVERSITY

UCL

Gift Agreement
between
SUKWOO ENGINEERING INC. of
SUKWOO Building, 88-13, Baumoe-ro 39-gil, Seocho-gu, Seoul, Republic of Korea.

And

University College London
Gower Street, London, WC1E 6BT

1. Description of the Gift

SUKWOO ENGINEERING INC. agrees to make a gift to University College London of £18000 to support the Mr Dong Hyun KIM in his doctoral studies *Quantifying the Value of Human Interaction-based LED Lighting on User Perception and Cognition.*

2. Payment of Gift
The Gift will be paid as follows:

- £ 6000 on or before 30 November 2014
- £ 6000 on or before 30 January 2015
- £ 6000 on or before 30 April 2015

The instalments will be paid by bank transfer, made payable to UCL Development Fund.

3. Stewardship and Recognition

Dr Kevin Mansfield (Principal Supervisor) will report to SUKWOO ENGINEERING INC about the impact their gift has made. The schedule of reports is as follows:

- 6 month progress report
- 12 month final report
- Submission of one paper to a peer-reviewed journal
- Submission of one conference paper

SUKWOO ENGINEERING *agrees to allow UCL to disclose their name and Gift amount for recognition purposes.*

4. Amendments

Any amendments to this agreement will be agreed in writing by both UCL and SUKWOO ENGINEERING INC.

5. Gift Acceptance Policy

This gift is subject to UCL's Guidelines for the Acceptance of Gifts and Donations, a copy of which is available on request.

6. Statement of Academic Freedom

It is a legal and moral requirement that philanthropic gifts do not afford the donor any expectation of benefit from the donation.

7. Spirit of the Gift Agreement

This Gift Agreement acts as a memorandum of understanding on the use of the donation upon receipt. This Gift Agreement supersedes all other agreements and understandings, both oral and written, between the parties relating to this gift. By signing this agreement the donor agrees to fulfil the pledge in a prompt and timely manner. If unforeseen circumstances prevent the donor from fulfilling the pledge, it is their responsibility to let UCL know as soon as possible.

Signed
SUKWOO ENGINEERING INC:

[redacted]

Name (please print) Signature Date

Signed
For and on behalf of UCL

Name (please print) Signature Date

Position

The UCL Development & Alumni Relations Office Data Protection statement is available at http://www.ucl.ac.uk/development/operations/data_protection. Please contact us if you would prefer a printed copy.

Appendix 3

Design brief document

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Dong Hyun Kim, PhD candidate
Institute for Environmental Design and Engineering
The Bartlett School of Environment, Energy and Resources, UCL
14 Upper Woburn Place, London, WC1X 0NN, UK

DESIGN BRIEF DOCUMENT (FOR THE LIGHTING DESIGNERS)

(1) Why is this design brief important?

You are invited to take part in a research study about enhancing occupants' psychological responses through office lighting design with emerging lighting technologies. Before explaining the procedures of this study, brief introduction (this part) is performed both in verbally and with this written document. The copy of the document will be provided to the participating lighting designers as a part of design brief. The aim of this brief in this study is to successfully communicate between the researcher (Dong Hyun Kim, PhD student at the Bartlett, UCL) and the lighting designers to clearly understand what the researcher would like to draw from the designers' knowledge and experience.

Please feel free to ask anytime regarding the study during the brief, which expects to take approximately an hour. I would like to deeply express my gratitude to you for deciding to participate the study.

(2) What is this study about and why is it important?

This study aims to create two different office lighting design schemes based on following psychological states, 'Lively' and 'Relaxing'. This is a part of study to test an emotion (or mood)-based approach to enhance office lighting design quality and ultimately users' experiences as well as their overall wellbeing.

Prior to the design brief section, it feels required to explain what the psychological dimension has been used and what 'Lively' and 'Relaxing' stands for in this dimension.

First, this study uses Russell's 'Circumplex Model of Affect' [1] as the model of psychological dimension and refers Boyce's concept of three different classifications [2] of lighting quality as a guideline to assess the perceived lighting design quality. Figure 1 shows how the Boyce's concept of lighting quality classifications is mapped on the Russell's Circumplex Model of Affect and two psychological states. It demonstrates how the current lighting recommendations have resulted in office users' moods, and how the current users' emotions could be enhanced through two different psychological states, 'Lively', and 'Relaxing'.

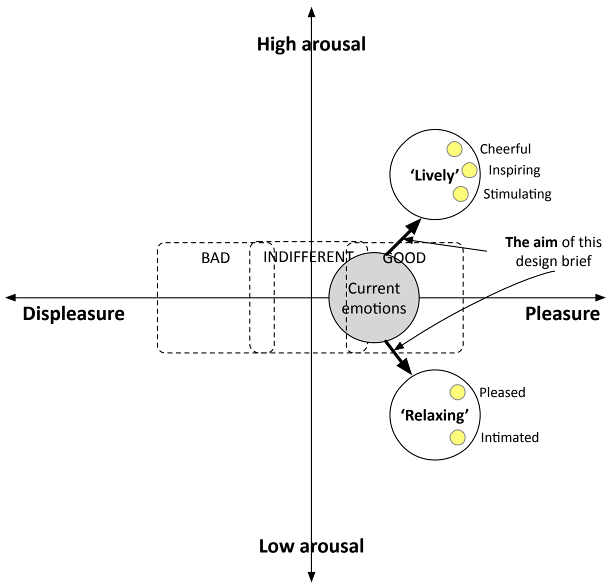


Figure 1. Two different psychological states mapped on the Circumplex Model of Affect

*: Dotted blocks represent the three classification of lighting quality [2] and grey circle represents the users' emotions under the current office lighting setting. White circles represent two different psychological states that this study aims to achieve through the lighting designers' participations. Lastly, yellow circles within the white circles are the correlated psychological states.

As shown in Figure 1, the Circumplex Model of Affect consists of two dimensions, level of pleasure and level of arousal. Therefore, **'Lively'** is in this context described as a sum of **high pleasure** and **high arousal** and **'Relaxing'** as a sum of **high pleasant** and **low arousal**.

More specifically, on office environments, 'Lively' lit environment has an aim to raise (or increase) users' concentration level at work whereas, 'Relaxing' lit environment' aim is to lower (or calm down) users' stress level when required.

As a participating lighting designer in this study, you are sought to produce improved office lighting design concepts (Step A: one for 'Lively' and one for 'Relaxing') on the following design brief.

(3) Design brief

As this study expects to find some patterns or characteristics from the lighting designers' design concepts to produce the detail design. The scope of the study has been narrowed down as following:

- The study only focuses on 'indoor office environments'
- Daylight or any other source of natural lights are excluded in this study
- The study uses a mock-up office (Attachment IV)

- In your design concept, the mock-up office should be a multi-function room, a mix of desk area and meeting area
- The open-plan office design is wanted, which is defined here as the place where users can move around the table or change locations rather than a fixed setting.

Your design concept should address the following points:
- The aesthetic qualities of your design should integrate well with interior and should complement the proposed furniture elements.
- Your design concepts should give the fundamental role of lighting in office environment: enhancing productivity and performance in the workplace.
- Your design concepts are encouraged to use the advantages of colour tunable lightings (which can also be programmed).
- Please do bear in mind that the study focuses on office lighting design. For example, lighting that is considered comfortable in an entertainment setting may be disliked and regarded as uncomfortable in a working space [3]

With regard to the preferred output of your design concept is as follows:
- Visually clear material that shows your concept; either hand-drawn sketch or computer-graphic generated (Such as PHOTOSHOP or ILLUSTRATOR) sketch (could be both, too)
- Your concept should clearly illustrate the mounting positions (such as height and direction) of all the light sources in the office layout (See Figure 9 for the size of the room)
  Note: although there is no specific luminaire or lamp shades prepared for the design materials, it is encouraged to suggest a simple lamp shade in your concept, which could control light distribution of the bulb more precisely
- Generally prefer A4 sized outputs but the size could be flexible up to individual preferences
- All the materials should be printed (or easily printable)
- Some written explanation of your concept would be welcomed

(4) Can I visit the mock-up office for more details?

The field study will start with an accompanied visit to the mock-up office on ____ July 2015, meeting outside the entrance of the Central House at ________.

Address: Central House, 14 Upper Woburn Place, London, WC1H 0NN
Nearest tube station is Euston or Euston square, then 5 minutes walk.

There will be significant opportunity to ask questions about the project scope, background and materials to be used in the mock-up office and your design concept.

References

[1] Russell, J.A. “A Circumplex Model of Affect”, *Journal of Personality and Social Psychology*, 1980, Vol 39, pp1161-1178.

[2] Boyce, P.R. *Human Factors in lighting*, 3rd edition, London and New York, Taylor & Francis, 2014.

ATTACHMENT I: Lighting-related materials

- 8 × ChromaWhite^{TM}; a colour tunable[*] ceiling lighting systems
- Up to 20 × GU10 bulbs (Philips Hue[**])
- Up to 20 × A19 bulbs (Philips Hue[**])
- Up to 10 × LED lightstrips (Philips Hue[**])

[*]: ChromaWhite^{TM} uses a colour tunable system from 2700K to 6500K, as well as high colour rendeing index avross the whole runing range

[**]: Philips Hue system offers a range of full colour spectrum tunable system (16 milion colours), therfore it is able to conrol hue, saturation and colour temperature with lower CRI value than ChromaWhite^{TM} lights. (See the Attachment III)

	Philips hue GU10 bulbs	Philips hue A19 bulbs
General description	Functional white light that can produce 16 million colours.	
Lumen output	145 lm @ 2000K	360 lm @ 2000K
	195 lm @ 2700K (default)	480 lm @ 2700K (default)
	210 lm @ 3000K	510 lm @ 3000K
	250 lm @ 4000K	600 lm @ 4000K
CRI	230 lm @ 6500K	550 lm @ 6500K
Beam angle	>80 (2000-4000K)	>80 (2000-4000K)
	-38^{o}	$-160^{o} \pm 20^{o}$

LED lightstrips (200 cm length) that can produce the same amount of colour changes as the other Philips hue bulbs.

General description	ChromaWhite™ is made of advance colour mix tecnology that delivers a peak colour rendering of Ra97, but never falling below Ra90 across the white tuning range, providing superior colour perception.
Characteristics	Minimum 93 @ 4000K and over 95 for the rest ranges

Page 5 of 12

ATTACHMENT II: Non lighting-related materials

- 40 × Lampholder with power sockets (upto 15m)
- 6 × Light stand with adjustable head
- 2 × 24inch LCD monitor (for a workstation)
- 1 × LCD 42inch TV screen with a stand
- 1 × Molo spacewall (for space partition and self-luminous wall, length upto 4.5m)
- Various formats of office desks, chairs, and sofas (See the below photos)

Lamp hoder with power socket (up to 15m)   Light stand with adjustable head

Molo spacewall (for partitioning and self-luminous objects)

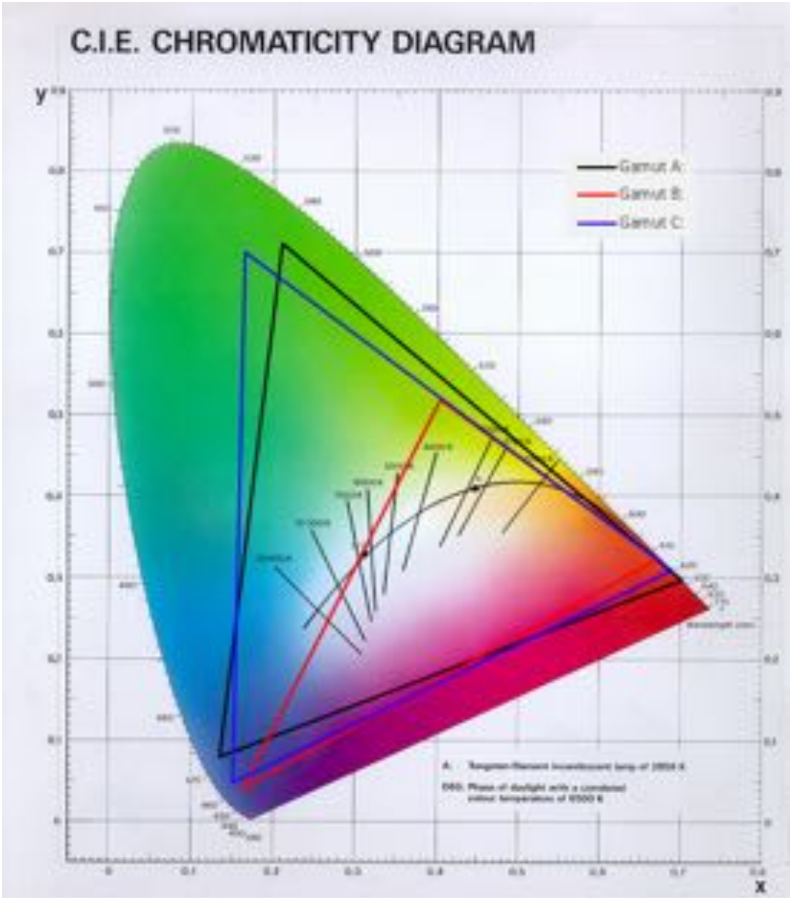

24inch LCD monitor (with a stand)


Optional office chair (type I)


Optional office table (low)


Optional office chair (type II)

ATTACHMENT III: The range of colour tunability (Philips Hue bulbs)



- All points on this plot have unique xy coordinates that can be used when setting the colour a hue bulb. If an xy value outside of bulbs relevant Gamut triangle is chosen, it will produce the closest colour it can make.
- Colour temperature is controllable from 2000 K to 6500 K.

ATTACHMENT IV: Physical layout of the mock-up office

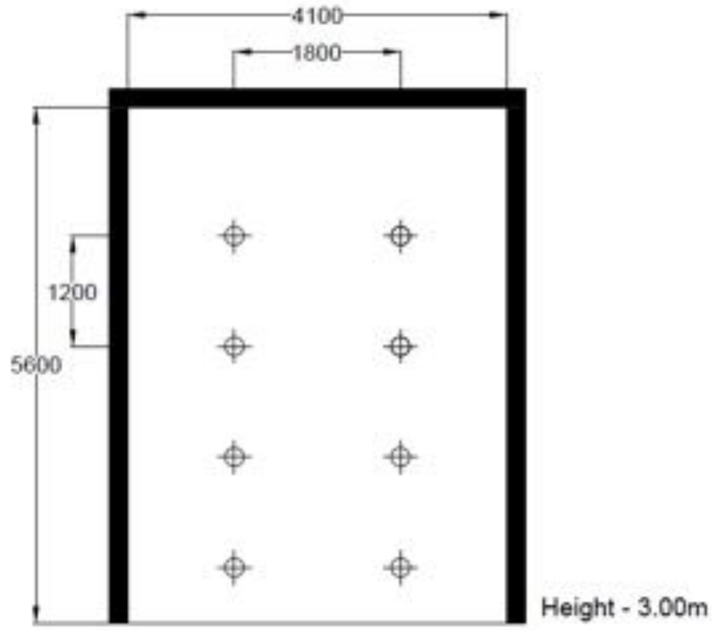
This attachment contains a simple floor plan of the Jevons room and four photos which takes from each side (at two different colour temperature).

Photo of the mock-up office (illuminated by ChromaWhite at 6500K)

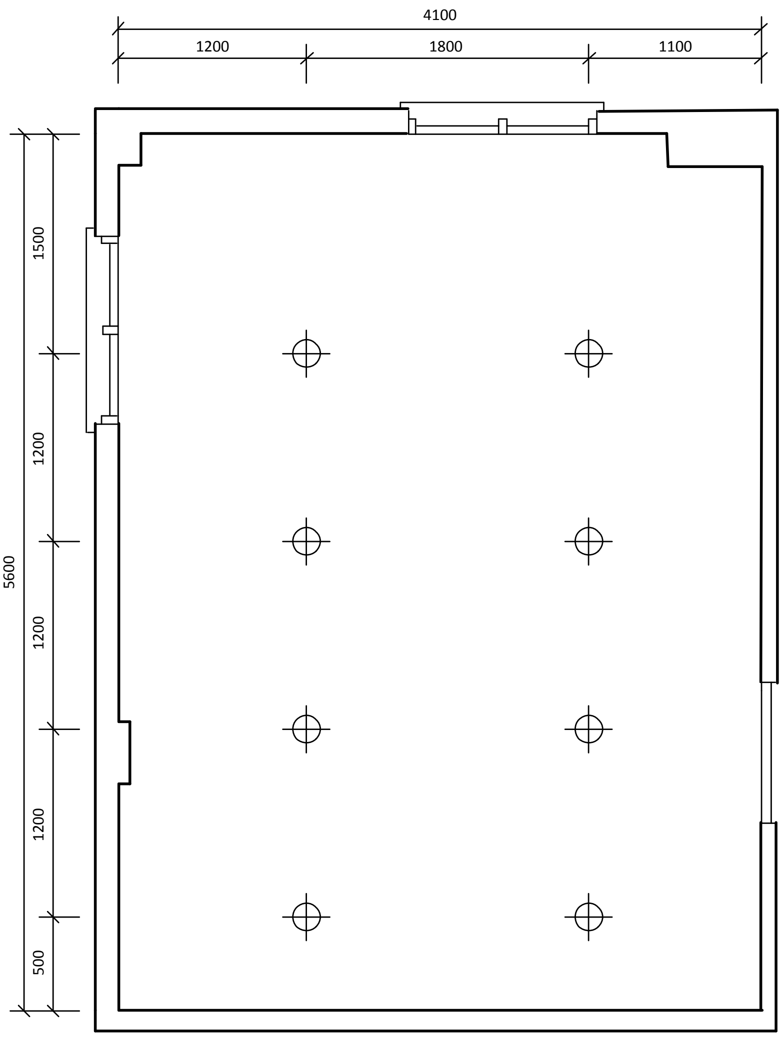
Photo of the mock-up office (illuminated by ChromaWhite 6500K)

Photo of the mock-up office (illuminated by ChromaWhite at 2700K)

Photo of the mock-up office (illuminated by ChromaWhite at 2700K)



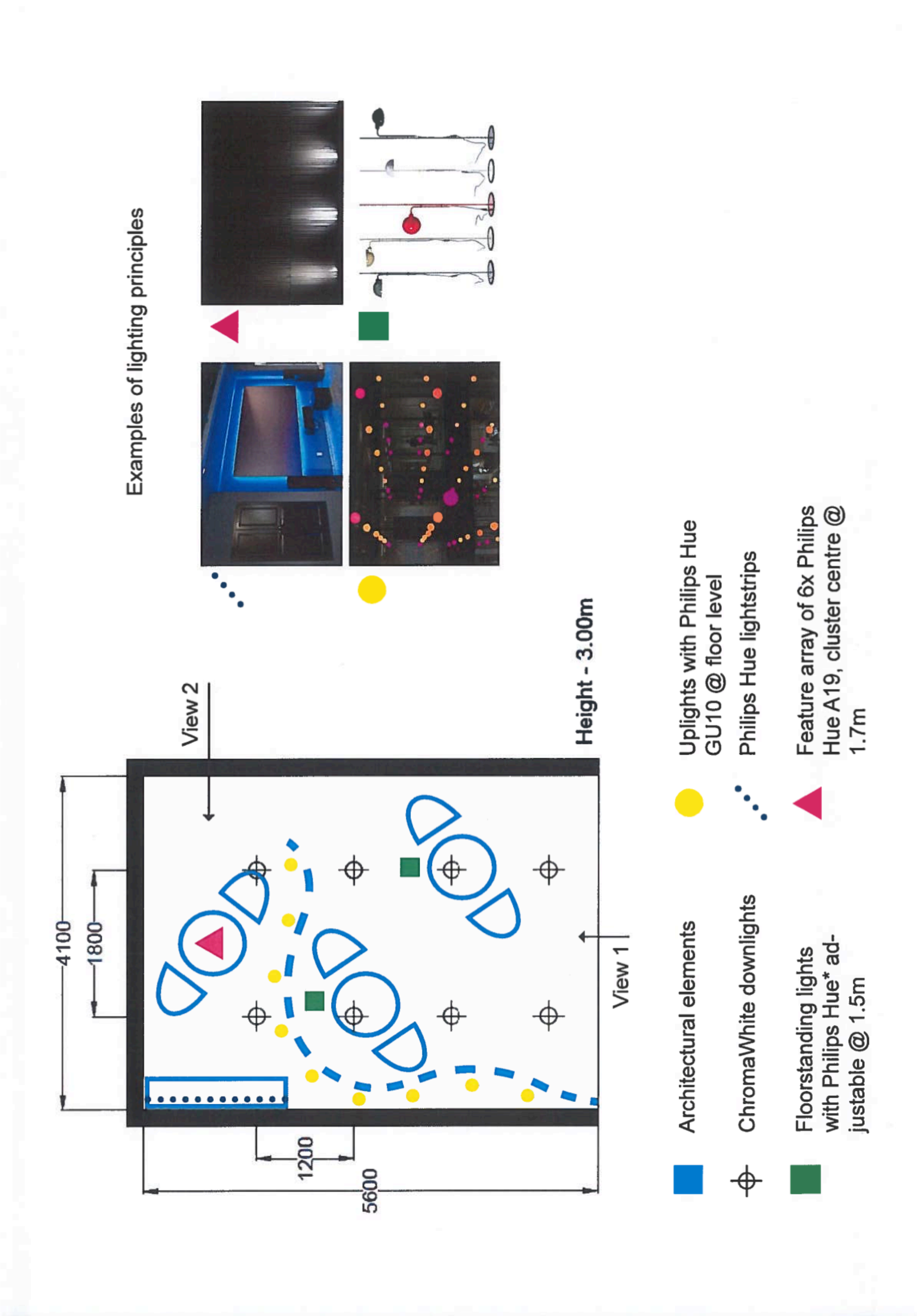
Floor plan of the mock-up office
*: Eight ceiling lightings (ChromaWhite) are displayed in the plan.



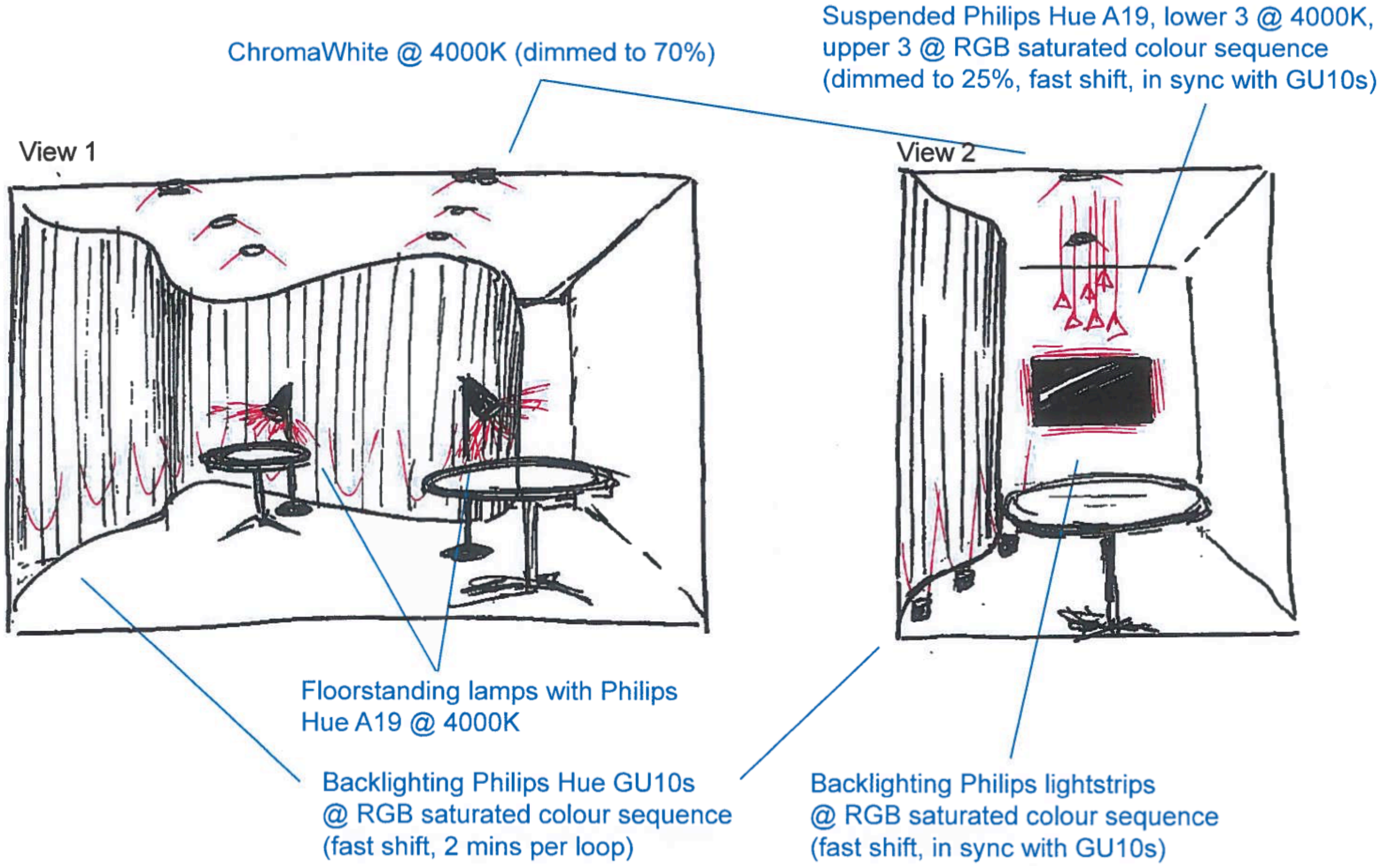
Floor plan of the mock-up office (larger version)

Appendix 4

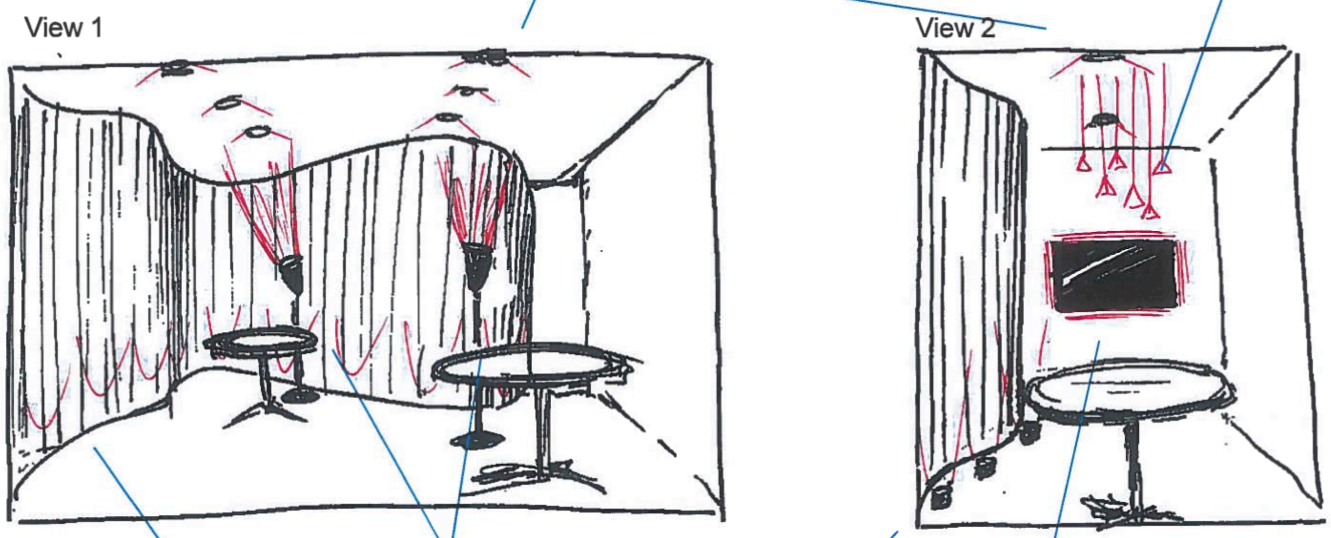
Designer 1's concepts of lively and relaxing spaces



Lively


View 1
View 2
ChromaWhite @ 4000K (dimmed to 70%)
Suspended Philips Hue A19, lower 3 @ 4000K, upper 3 @ RGB saturated colour sequence (dimmed to 25%, fast shift, in sync with GU10s)
Floorstanding lamps with Philips Hue A19 @ 4000K
Backlighting Philips Hue GU10s @ RGB saturated colour sequence (fast shift, 2 mins per loop)
Backlighting Philips lightstrips @ RGB saturated colour sequence (fast shift, in sync with GU10s)

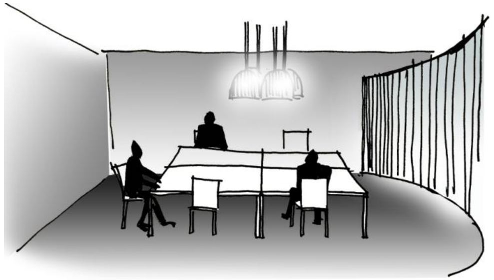
Relaxing


ChromaWhite @ 3000K (dimmed to 70%)
Suspended Philips Hue A19, lower 3 @ 3000K, upper 3 @ RGB pastel tone colour sequence (dimmed to 25%, slow shift, in sync with GU10s)
View 1
View 2
Floorstanding lamps with Philips Hue GU10 @ RGB pastel tone colour sequence (show shift, 5 mins per loop)
Backlighting Philips Hue GU10s @ 3000K-6000K CCT sequence (very show shift, 30 mins per loop)
Backlighting Philips lightstrips @ RGB pastel tone colour sequence (show shift, in sync with GU10s)

Appendix 5

Designer 2's concepts on lively and relaxing spaces

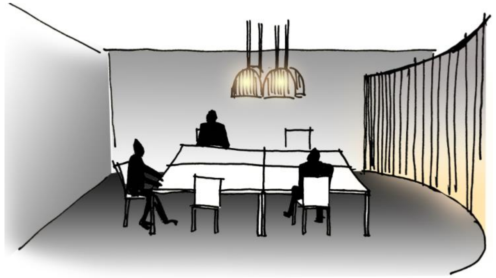
LIGHTING SCENES



LIVELY MODE : TABLE TASK

800 – 1000 lux
Normal white 4000K

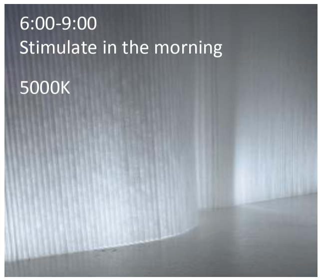
High light level and white light to motivate the user and to help them concentrate on doing their task and increase their performance.

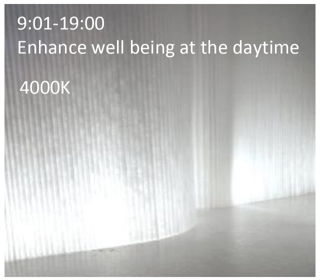


RELAX MODE : COMMUNICATIVE TASK

300 – 500 lux
Warmwhite 3000K

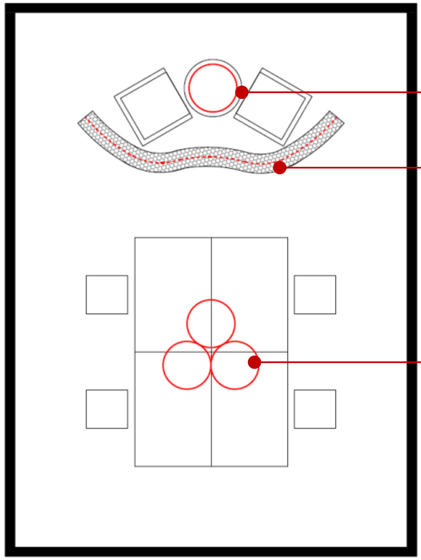
Lower lighting level and warmwhtie, 3000K make people skin tone look healthy and the ambient light is bright enough to see facial interaction.





Illuminated partition lighting using tuneable white with subtle change according to time of the day will provide ambient light to add a visual interest and dynamic in the space for people to look up.

MATERIALS



A. Suspension lighting over the desks

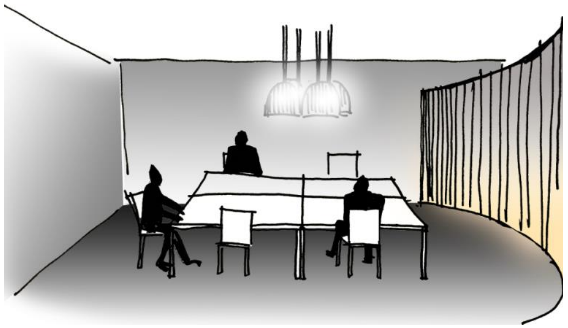
B. Paper partition illuminated with colour change linear LED installed at the base to uplight the wall.

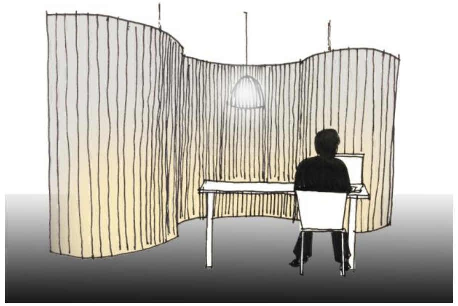
A. Suspension lighting over the desks

A. White paper lampshade for Philips hue A19

B. Illuminated partition with colour change LED stripe

White ceiling hook





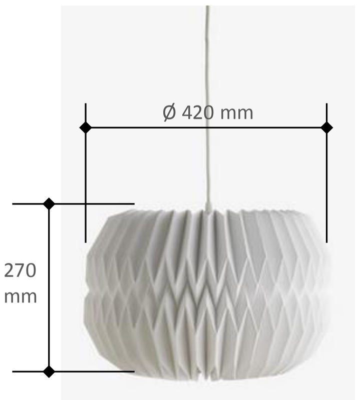
LIGHTING DETAILS

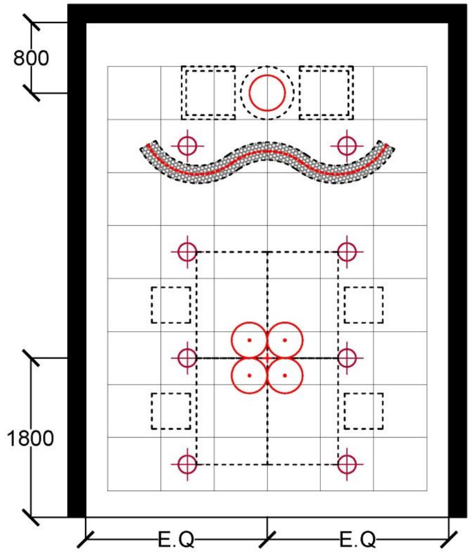
Existing downlight

A. White paper lampshade

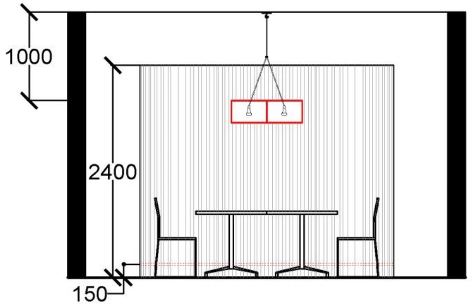
B. Linear LED installed in the partition

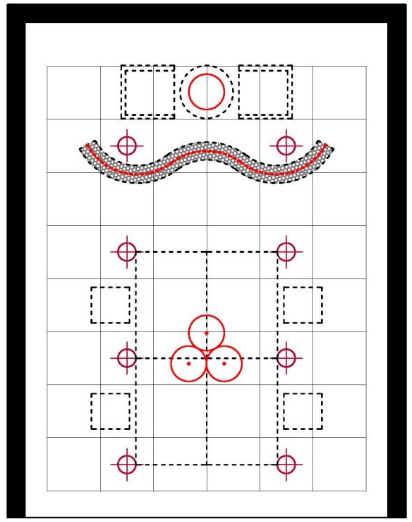
A. White paper lampshade dimension



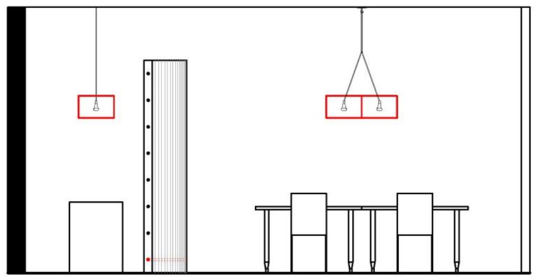


Option 1 - Fixed



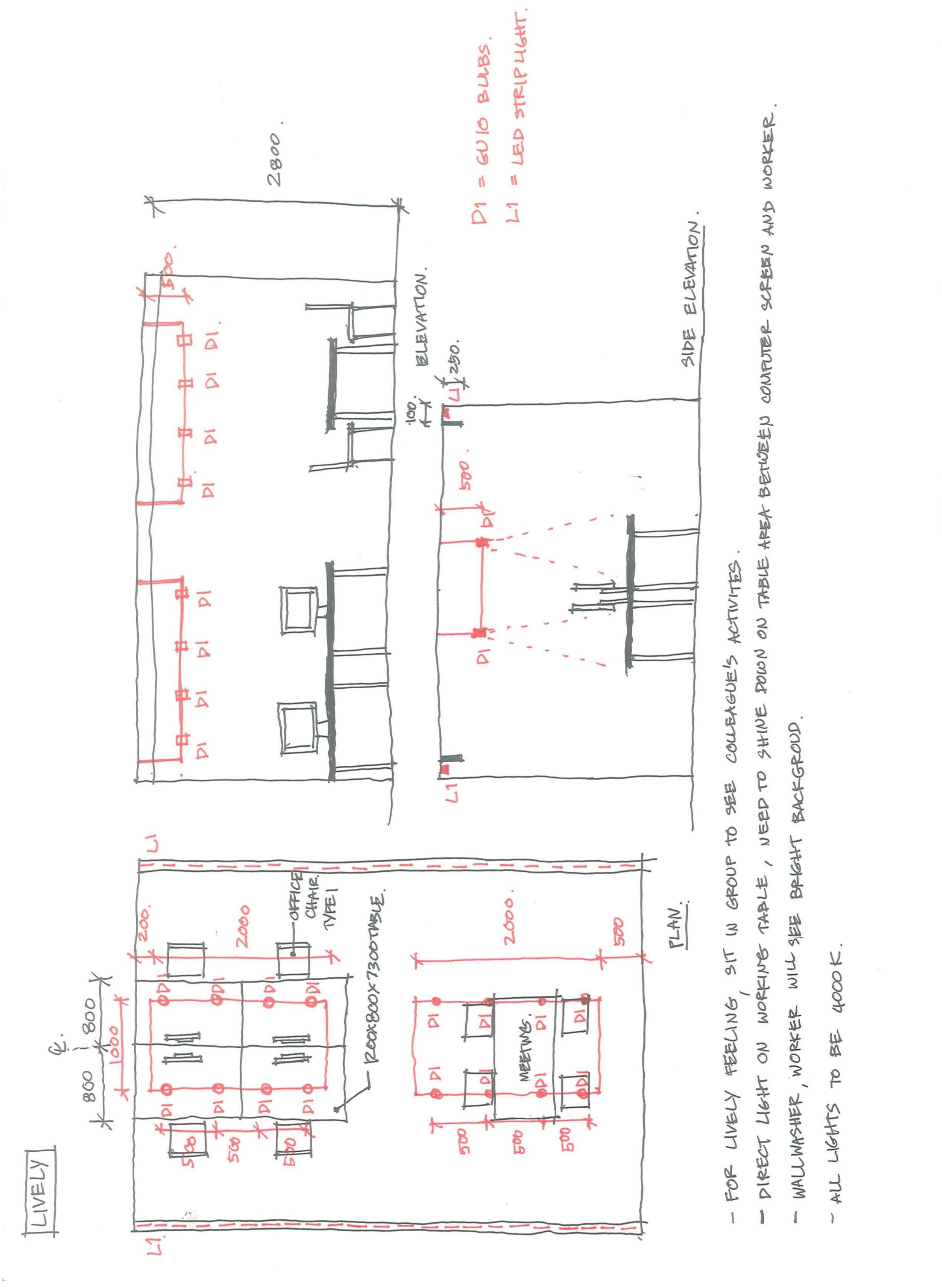


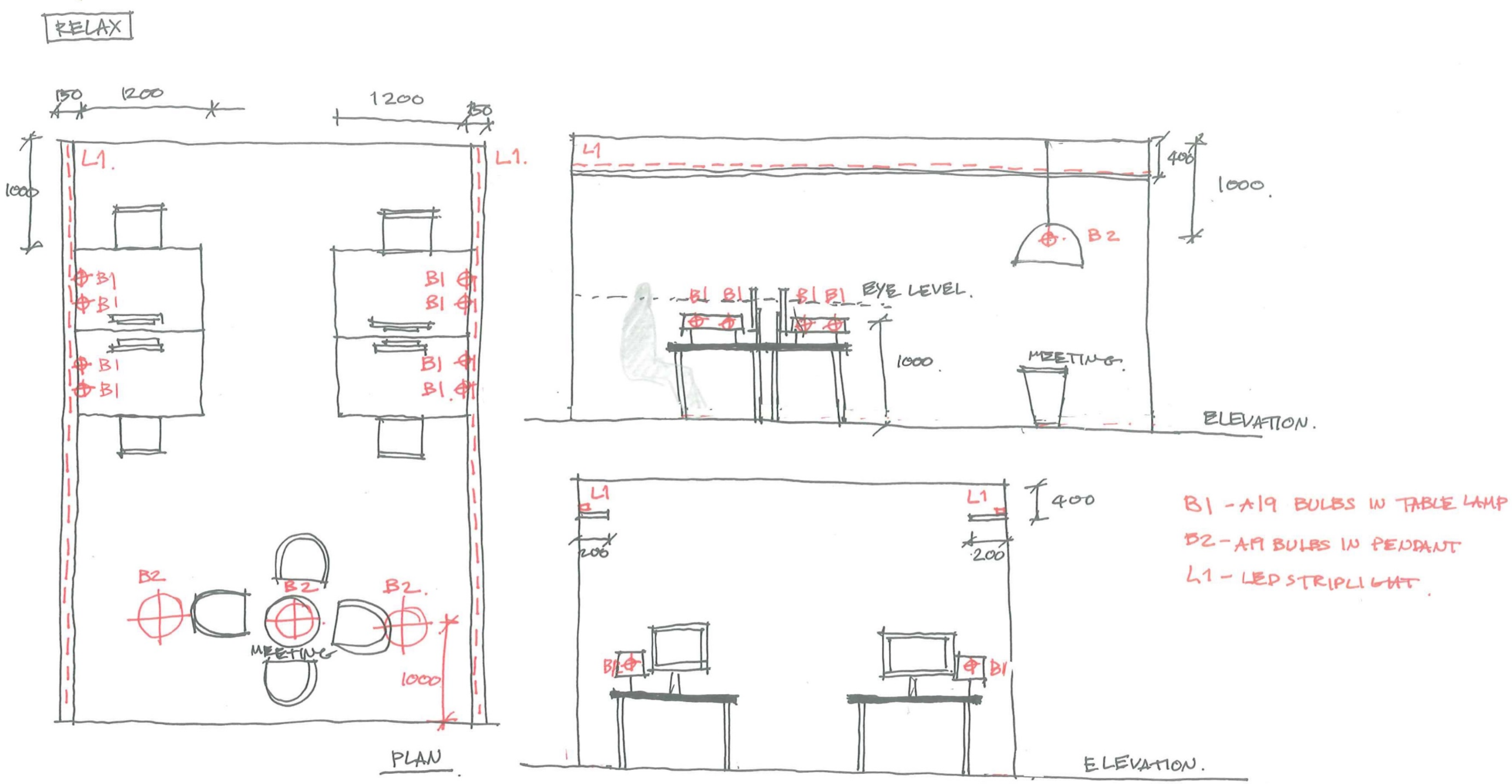
Option 2 - Movable



Appendix 6

Designer 3's concepts on lively and relaxing spaces



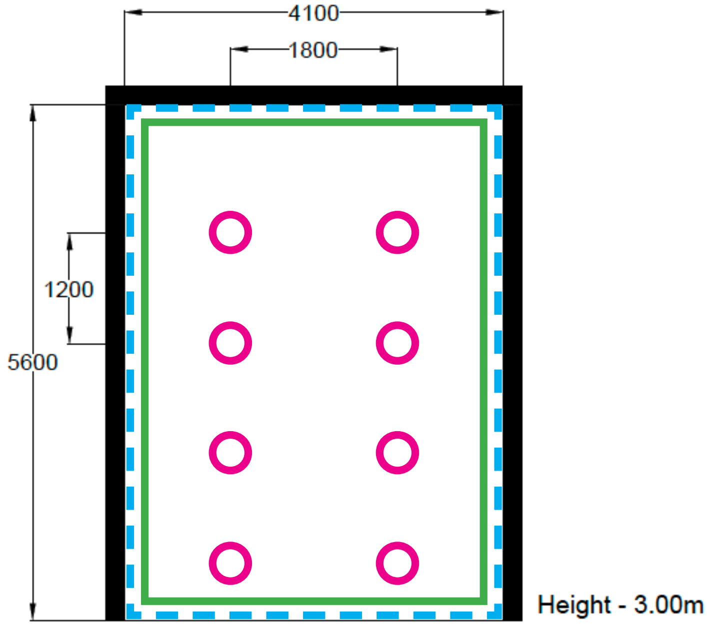


- FOR RELAX SCENE, WORKERS GET THEIR OWN SEATING SPACE
- ALL LIGHTS TO BE 2700K.
- NO DIRECT LIGHT AND LIGHT SHOWN AT EYE LEVEL, LIGHT WOULD SHINE ON TASK AREA ONLY. (WORKING TABLE).
- ALL LIGHTS TO BE CONCEALED INSIDE LAMP SHADE OR INTERIOR DETAIL.

Appendix 7

Designer 4's concepts on lively and relaxing spaces

Lively

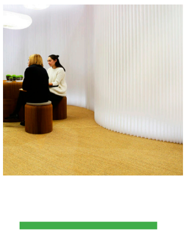


Floor plan of the mock-up office

*: Eight ceiling lightings (ChromaWhite) are displayed in the plan.

Indicative Lighting Layout

Colour changing (white & blue) LED strip concealed at the perimeter of the ceiling to backlit the translucent material.



Molo spacewall covering all the wall surface.

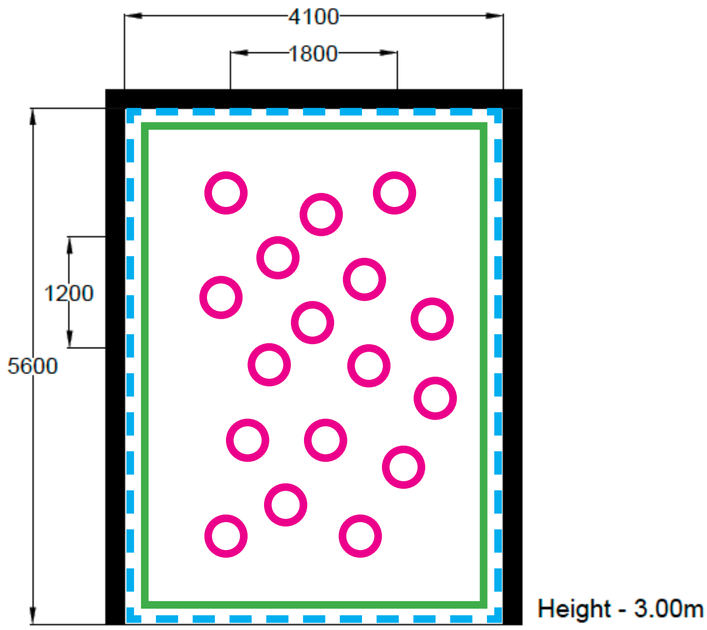
Cool white (5000k) LED downlights providing functional lighting.

Lively

THIS IS LIGHT

Indicative Perspective

Relaxing



Floor plan of the mock-up office

*: Eight ceiling lightings (ChromaWhite) are displayed in the plan.

Indicative Lighting Layout

Colour changing (white & yellow) LED strip concealed at the perimeter of the floor to backlit the translucent material.

Molo spacewall covering all the wall surface.

Warm white (2700k) LED pendent luminaires suspend at a height of 2.5-2.8 m providing functional lighting.

Relaxing

Indicative Perspective

Appendix 8

Designer 5's concepts on lively and relaxing spaces

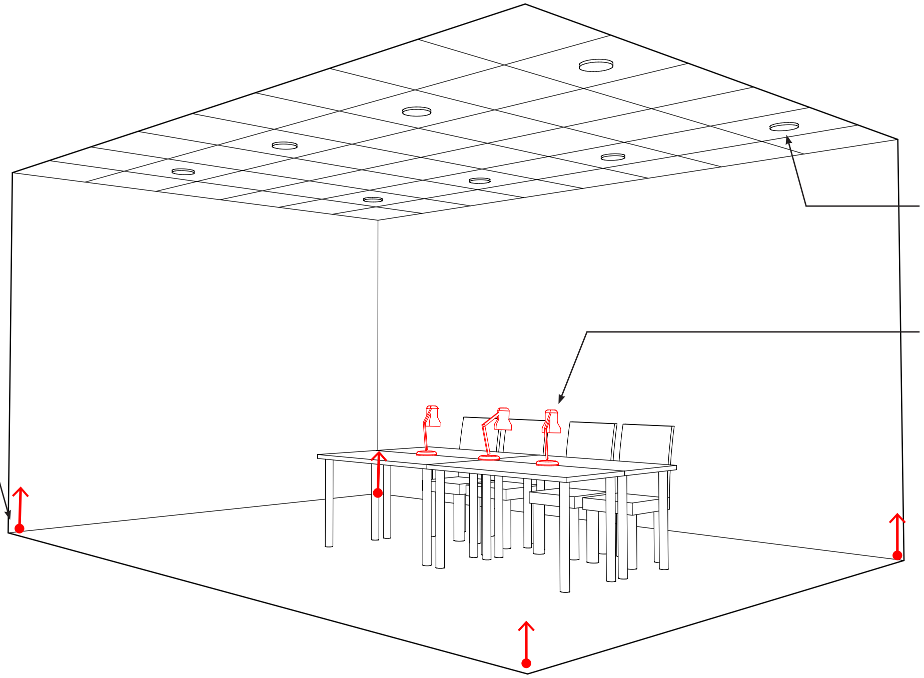
Relaxing Scheme

Lighting Concept and Objectives:

- To create a setting for quiet study and calmness by evoking ideas of 'work by candlelight' and 'burning the midnight oil'.
- Lighting aims to achieve this by using mainly warm white CCT to mimic incandescence.
- Light is used sparingly in order not to overlight the space. Localised desk lamps are suggested to focus light onto work surfaces and avoid over-lighting wall surfaces.

Key Words:

- Warm/ incandescent
- Low lit
- Focused lighting
- Private Study



Room downlights set to 0% output.

Localised freestanding desk lamps.
Utilising Philips Hue A19 lamps, set at 2700K, 100% output

Floor corner uplighters, to provide narrow beam accent light at each room corner for indirect atmospheric effect.
Utilising Philips Hue GU10 lamps, set at 2000K, 100% output
(Additional lamps can be arranged around room if light levels are too low).

Incandescent light sources help to evoke feeling of indoors and quiet study.

Precedent / Mood Images

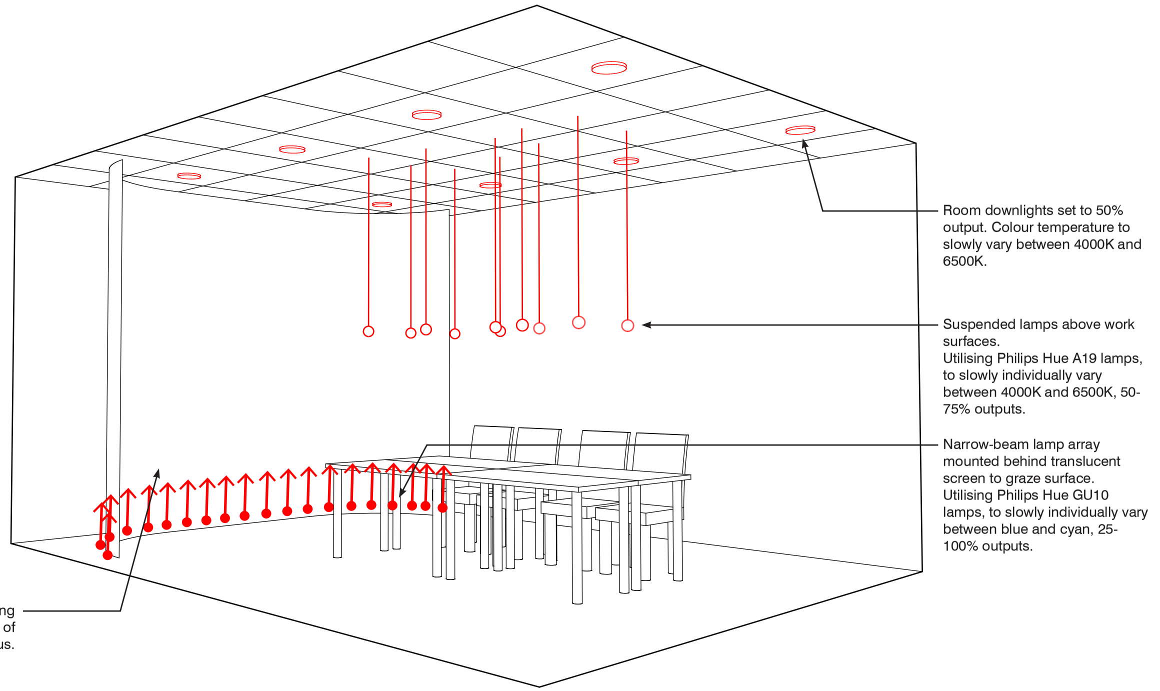
Lively Scheme

Lighting Concept and Objectives:

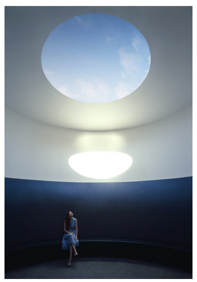
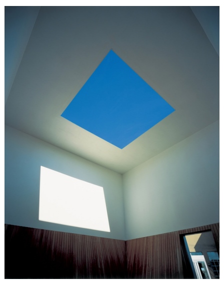
- To create a setting for stimulation. Lighting scheme will aim to create a sense of time passing and to create an artificial connection with the outside.
- Light sequencing at screen is to give the impression of activity happening beyond, as if a curtain is covering a window to the outside. Blue coloured lighting will predominantly be used to stimulate the occupants' alertness and give an impression of skylight.
- Suspended lamp sequencing is to give an impression of clouds passing overhead. This will be achieved by randomly varying the lumen outputs and colour temperature (to vary between 4000K and 6500K).

Key Words:

- Vivid/ Clear
- Bright/ Stimulating
- Sharp
- Dynamic/ Changeable
- Blue - circadian stimulation
- Skylight



Indirect lighting onto blue surface and gobo lighting creates the illusion of sunlight penetrating a space.

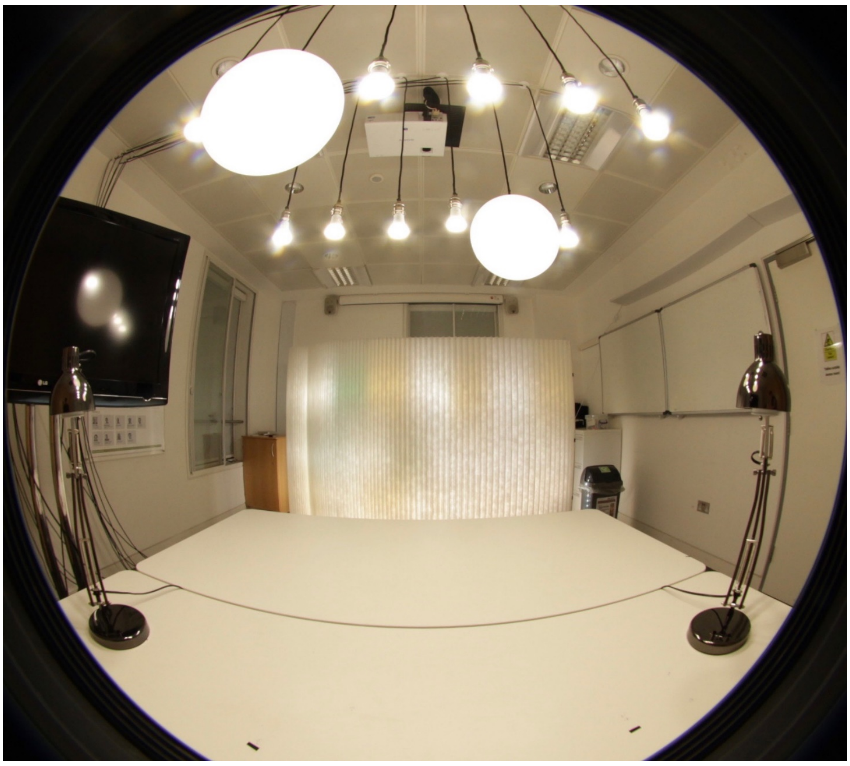




Precedent / Mood Images

Appendix 9

Photographs of 'lively' and 'relaxing' settings

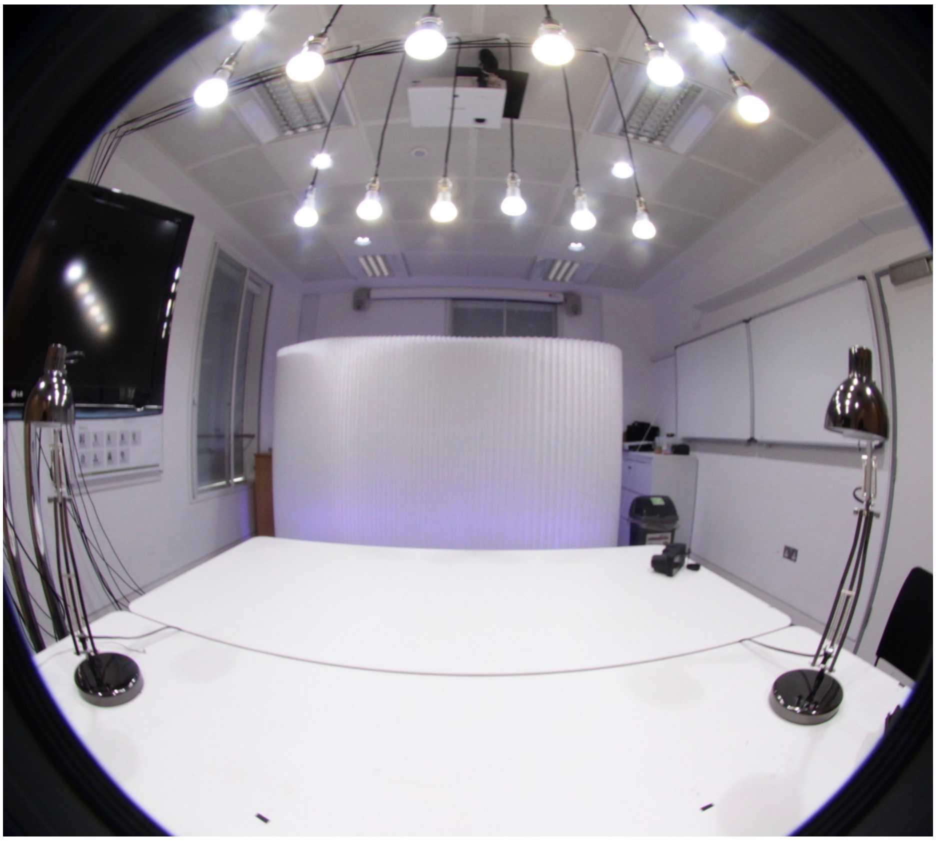
Lively setting 1



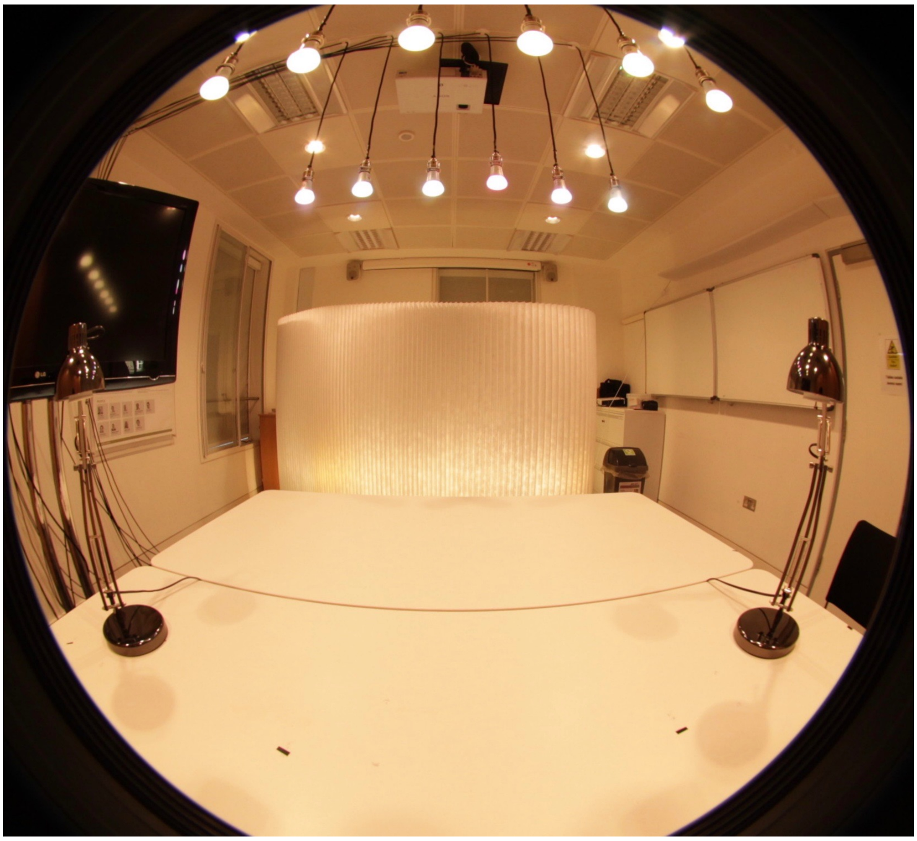
Lively setting 2

Lively setting 3

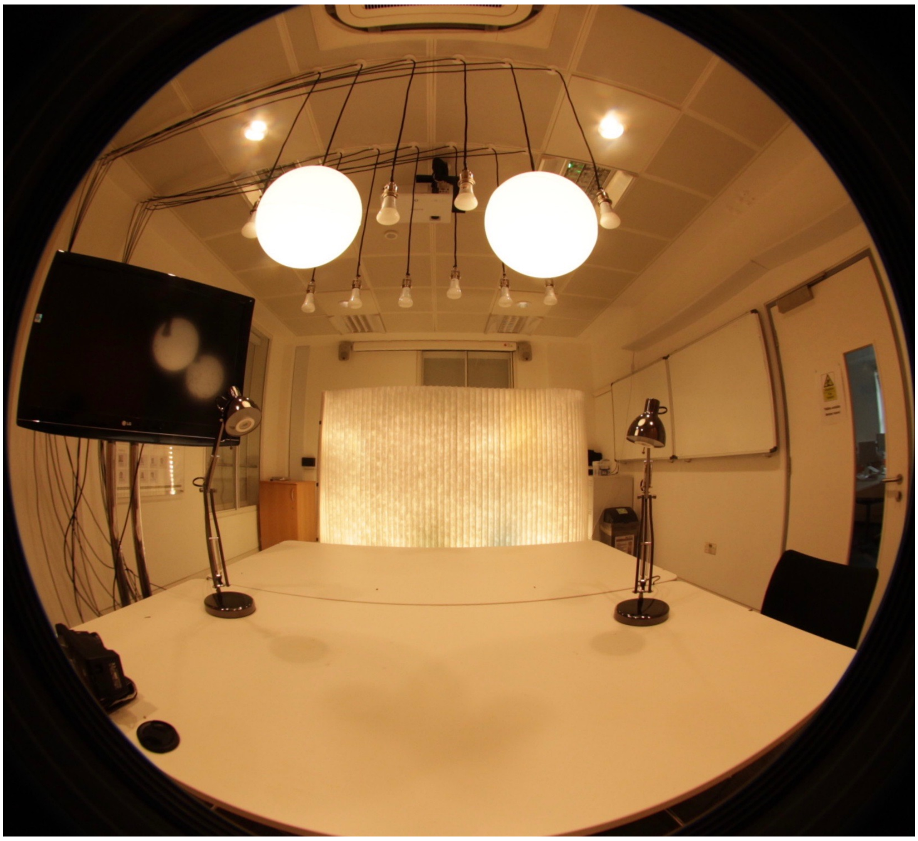
Lively setting 4



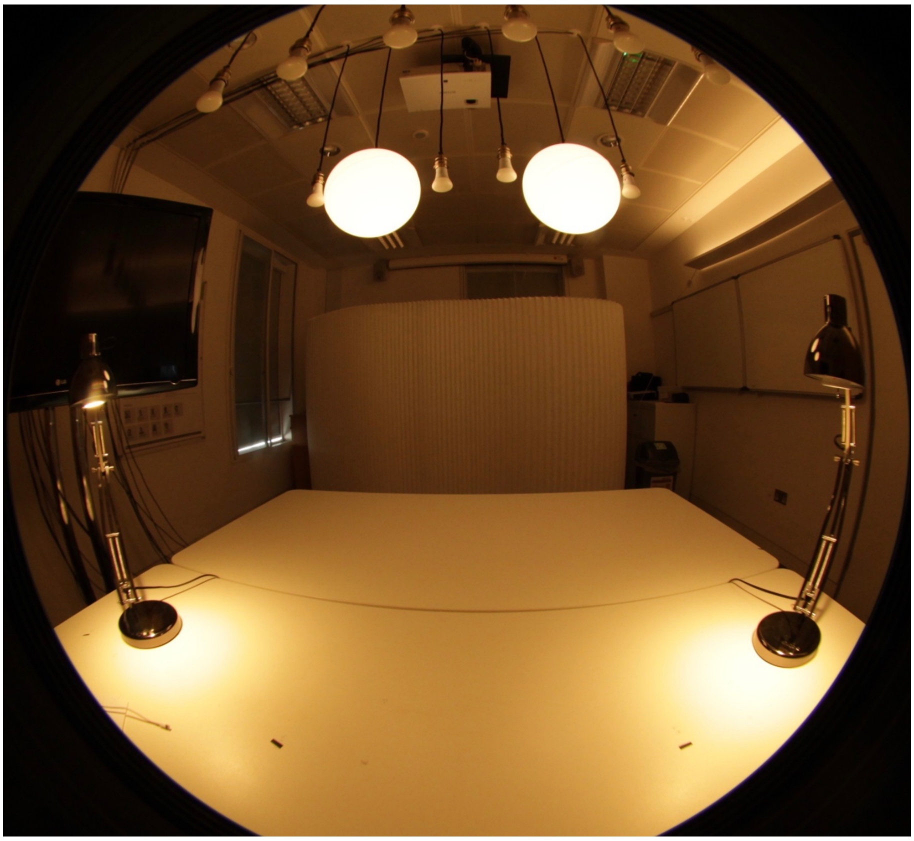
Lively setting 5



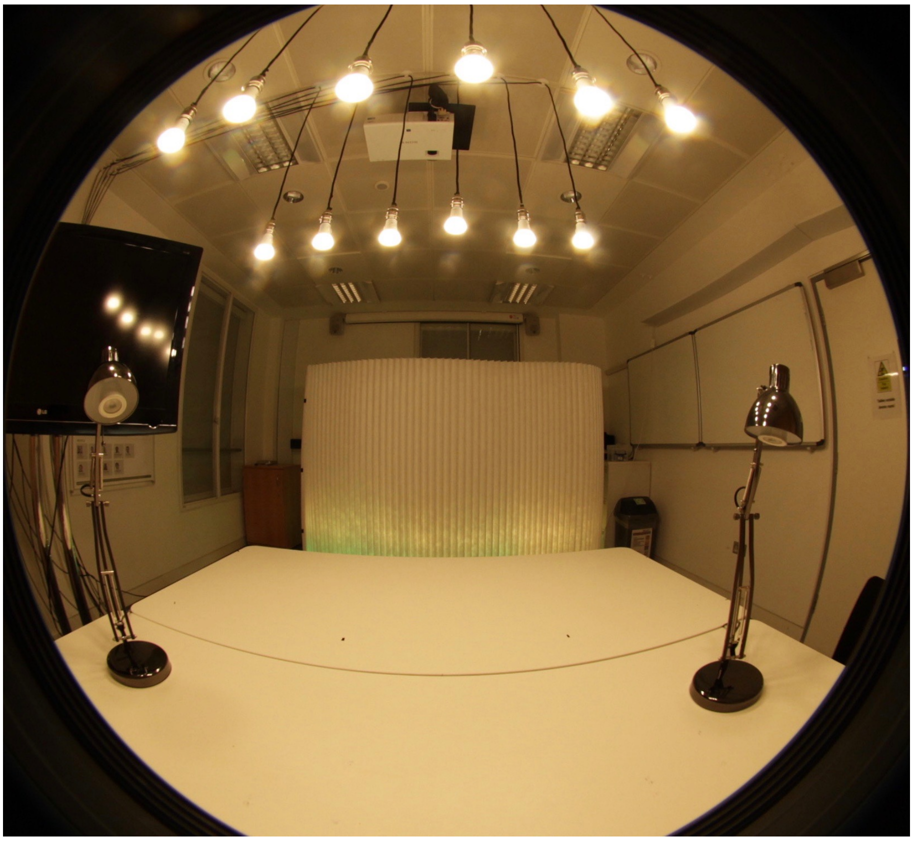
Relaxing setting 1



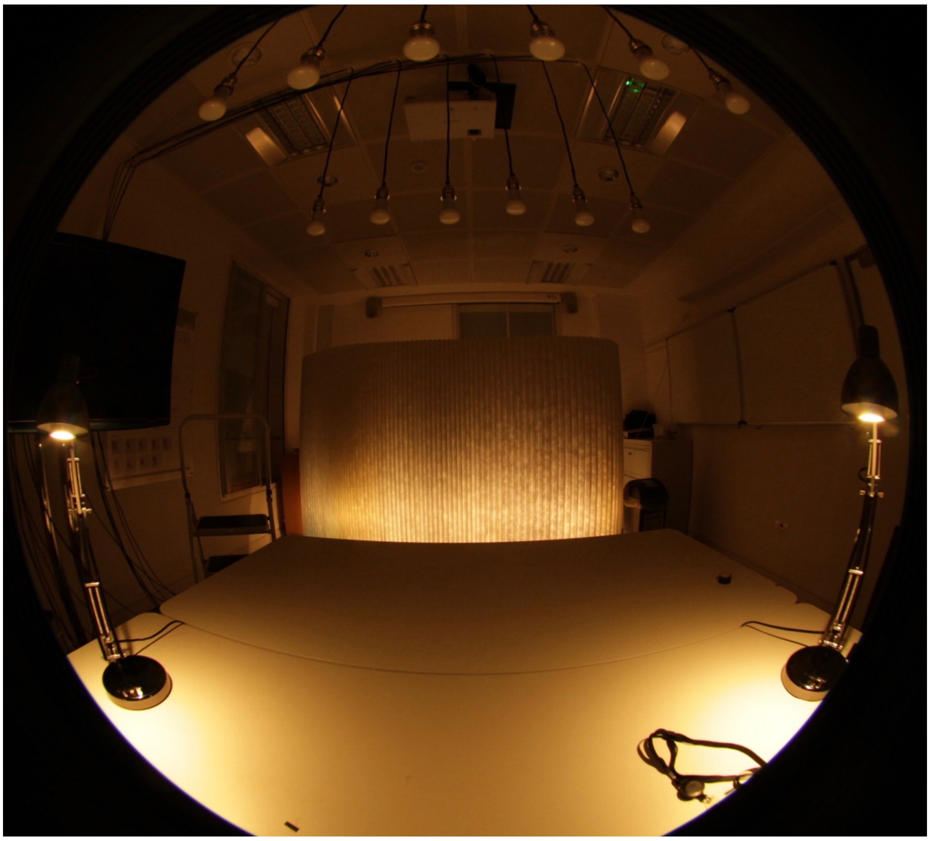
Relaxing setting 2



Relaxing setting 3



Relaxing setting 4

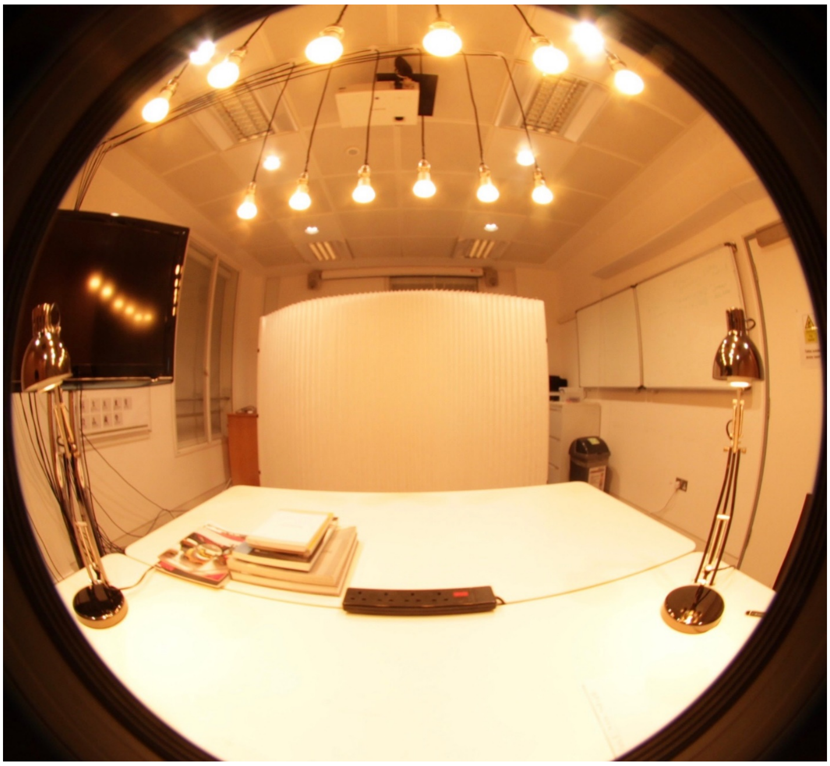


Relaxing setting 5

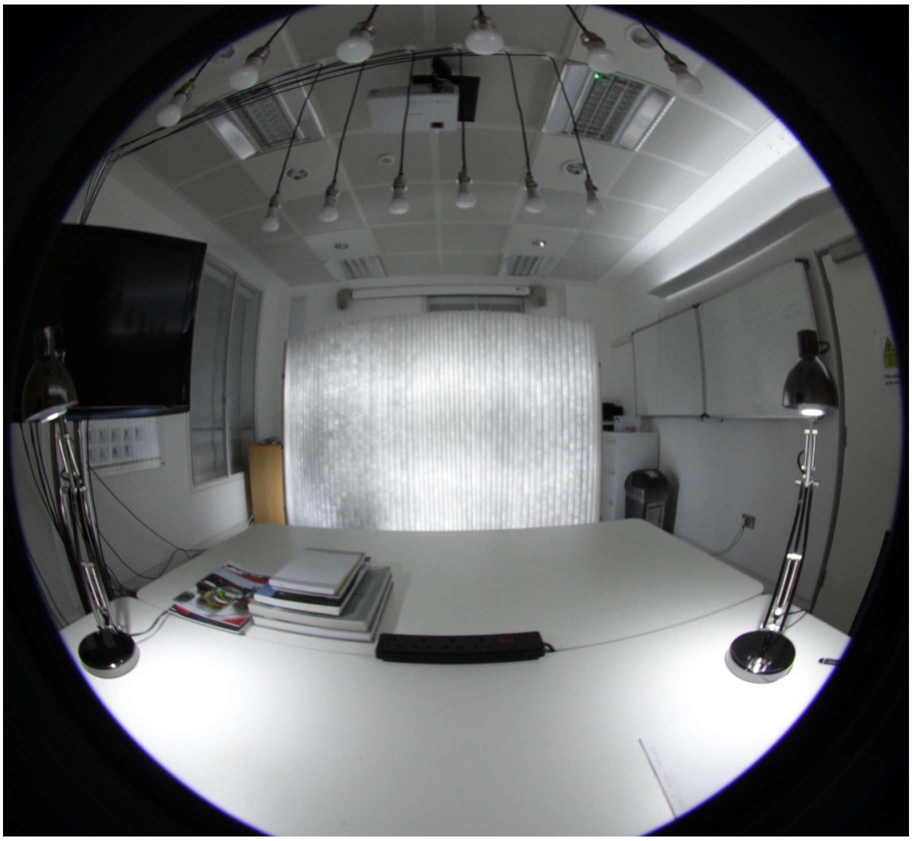
Appendix 10

Photographs of ‘miscellaneous’ settings

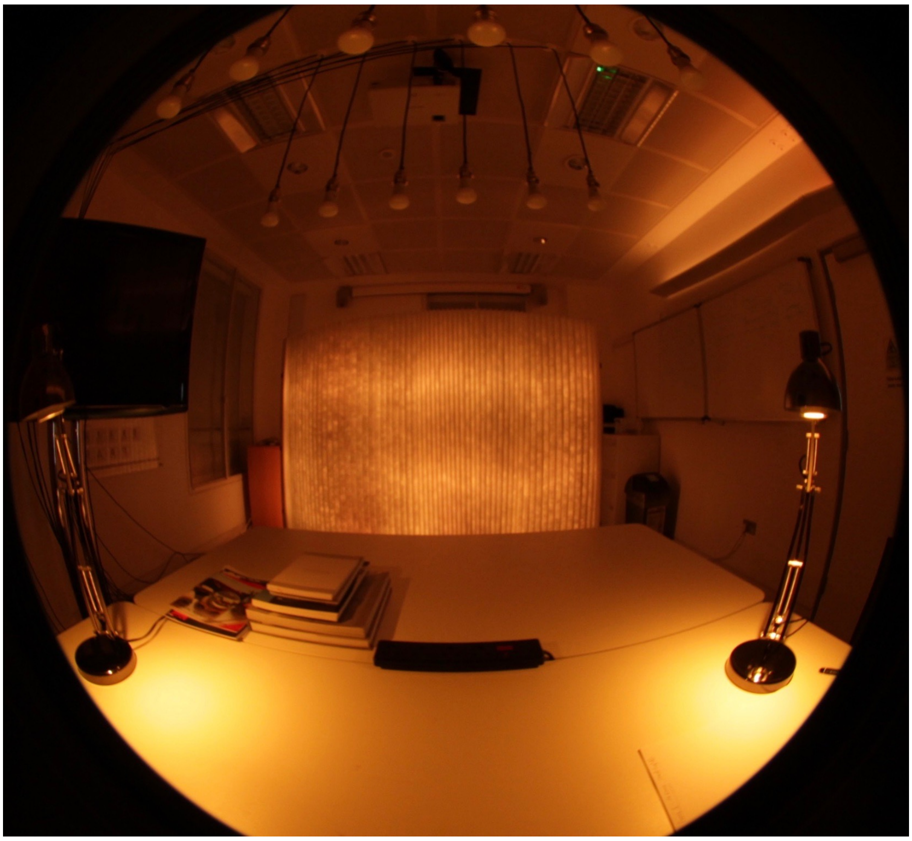
Miscellaneous setting 1



Miscellaneous setting 2



Miscellaneous setting 3



Miscellaneous setting 4

Miscellaneous setting 5

Appendix 11

Questionnaire for field study: phase II

The Bartlett School of Environment, Energy and Resources
Institute for Environmental Design and Engineering
14 Upper Woburn Place, London, WC1H 0NN

UCL

Questionnaire: Phase II

Study Number: (UCL Ethics Project ID Number 7101/001)
Principal researcher: Dong Hyun Kim (Mob: 07837980233, Email: dong.kim@ucl.ac.uk)
Participant Reference Number for study:
Scene No:

Introduction

Thank you in advance for taking your time to complete this questionnaire. As explained in the introductory session earlier today, you will be asked to fill in this questionnaire for each session. There are in total 15 sessions and each session approximately takes 15 minutes. Therefore, a completion of the whole experiment will take approximately 5 hours in total, including in-between break.
Please feel free to ask any query or makes some request to the principal researcher anytime during the experiment. This questionnaire is only used for statistical analysis of my research as a part of PhD thesis.

In this question, you are asked to assess your ***current feeling*** by putting a circle the adjective(s) in the below box that describe your *feelings most* closely. Multiple choices are allowed and if you wish to describe your impressions by using your own adjectives, please write down any additional words in the line below. Example sleepy

Tense	Delightful	Energetic	Miserable	Sleepy	Enthusiastic
Gloomy	Calm	Annoying	Placid	Jittery	Depressive
Quiet	Exciting	Pleasing	Sluggish	Satisfying	Sad
Activating	Elating	Stressful	Boring	Unhappy	Dissatisfying

Mark on the below scales how you feel about the ***appearance of the room***. For each pair, put a mark (see example) close to adjective which you believe to describe your feelings. The more one adjective describes your perceived appearance, the closer you should place your mark to it. Example ✓

	Completely		Moderately		Neutral		Moderately		Completely	
Bright	◯	◯	◯	◯	◯	◯	◯	◯	◯	Dim
Uniform	◯	◯	◯	◯	◯	◯	◯	◯	◯	Non-uniform
Uninteresting	◯	◯	◯	◯	◯	◯	◯	◯	◯	Interesting
Chilly	◯	◯	◯	◯	◯	◯	◯	◯	◯	Warm
Dramatic	◯	◯	◯	◯	◯	◯	◯	◯	◯	Diffuse
Spacious	◯	◯	◯	◯	◯	◯	◯	◯	◯	Confined

End of the first sub-session. Please follow the instructions before turning over the page.

Considering the lighting in this workspace, please rate ***lighting quality*** by placing a mark on the scales below. **Note** that you are comparing this scene to the **default** scene when asked to assess the appearance.

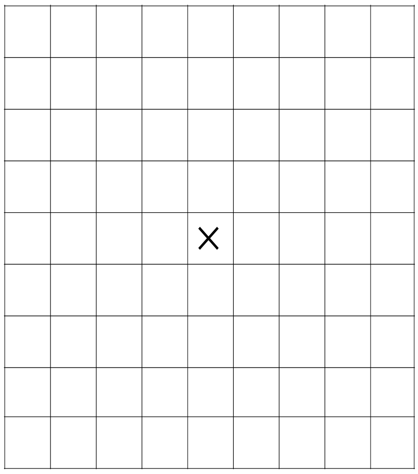
Example ✓

	Not at all	A little	Moderately	Very much	Completely
Does the presence of the lighting make the space more attractive?	○	○	○	○	○
Does the colour appearance of the lightings make the room more attractive?	○	○	○	○	○
Overall, would you consider this workspace comfortably lit if you were staying for a few hours?	○	○	○	○	○
Overall, how satisfied are you with lighting in this space?	○	○	○	○	○
	Very poorly	Poorly	Acceptable	Well	Very well
Additionally, how does the lighting render the person sitting next you (for conference use)?	○	○	○	○	○

Use the grid below to describe your ***current emotion*** by marking a 'X'. The centre of the grid (marked with 'X') represents a neutral, average, everyday kind of feeling. It is neither positive nor negative.

Very high activation

Very high unpleasantness



Very high pleasantness

Very high sleepiness

Please move to the waiting area and wait for 10 seconds and rate your perceived *eyestrain* by placing a mark on the scale below.

Example ✓

	Not at all	A little	Moderately	Very much	Completely
I am experiencing negative sensitivity to light from eye discomfort.	○	○	○	○	○
I am experiencing either of redness or soreness in the eyes	○	○	○	○	○
I am experiencing tired eyes.	○	○	○	○	○
I am experiencing dryness in the eyes.	○	○	○	○	○

Please feel free to *comment* on the below box on any aspect, positive or negative, of this session's experience.

Thank you for your participation in the study. This is the end of the first sub-session in the study.
The next session will start after short 3-5 minutes of the break time.